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Citation for published version:

Brader, M, Lloyd, JM, Barlow, NLM, Norddahl, H, Bentley, MJ & Newton, A 2017, 'Postglacial relative sea-level changes in northwest Iceland: Evidence from isolation basins, coastal lowlands and raised shorelines', *Quaternary Science Reviews*, vol. 169, pp. 114–130. <https://doi.org/10.1016/j.quascirev.2017.05.022>

Digital Object Identifier (DOI):

[10.1016/j.quascirev.2017.05.022](https://doi.org/10.1016/j.quascirev.2017.05.022)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Peer reviewed version

Published In:

Quaternary Science Reviews

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Postglacial relative sea-level changes in northwest Iceland: Evidence from isolation basins, coastal lowlands and raised shorelines

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Abstract Relative sea-level (RSL) data provide constraints on land uplift associated with former ice loading and can be used to differentiate between contrasting ice unloading scenarios. Isolation basin, coastal lowland and geomorphological evidence is employed to reconstruct RSL changes in northwest (NW) Iceland, which may have experienced contrasting uplift patterns. Under local (NW) uplift, highest RSL would be expected in central Vestfirðir, whereas highest RSL would be closest to the main ice-loading centre under regional (central Iceland) uplift. Four new RSL records are presented based on 16 sea-level index points and 4 limiting ages from sites principally focussed along a transect away from central Iceland. The new RSL records highlight spatial variability of Holocene RSL changes and provide constraints on deglaciation. There is an increase in marine limit elevation with proximity to the proposed principal ice loading centre in central Iceland. Highest recorded marine limit shorelines are found in Hrútafjörður-Heggstaðanes (southeast), the lowest in Hlíðuvík and Rekavík bak Látrum (north), and at an intermediate elevation in Reykjanes-Laugardalur (central Vestfirðir). Evidence from Breiðavík-Látrar records early rapid deglaciation in Breiðafjörður or a complex interplay of multiple uplift centres. RSL fell rapidly following deglaciation in several locations as a result of the quick response of the Icelandic lithosphere to unloading. The RSL data along the transect show an uplift pattern consistent with extensive regional glaciation emanating from central Iceland, which could have implications for ice sheet configuration and patterns of deglaciation, glacio-isostatic adjustment modelling and the volume of meltwater input into the North Atlantic.

Keywords

Holocene; sea level changes; Europe; Micropalaeontology, diatoms; isolation basin; Iceland

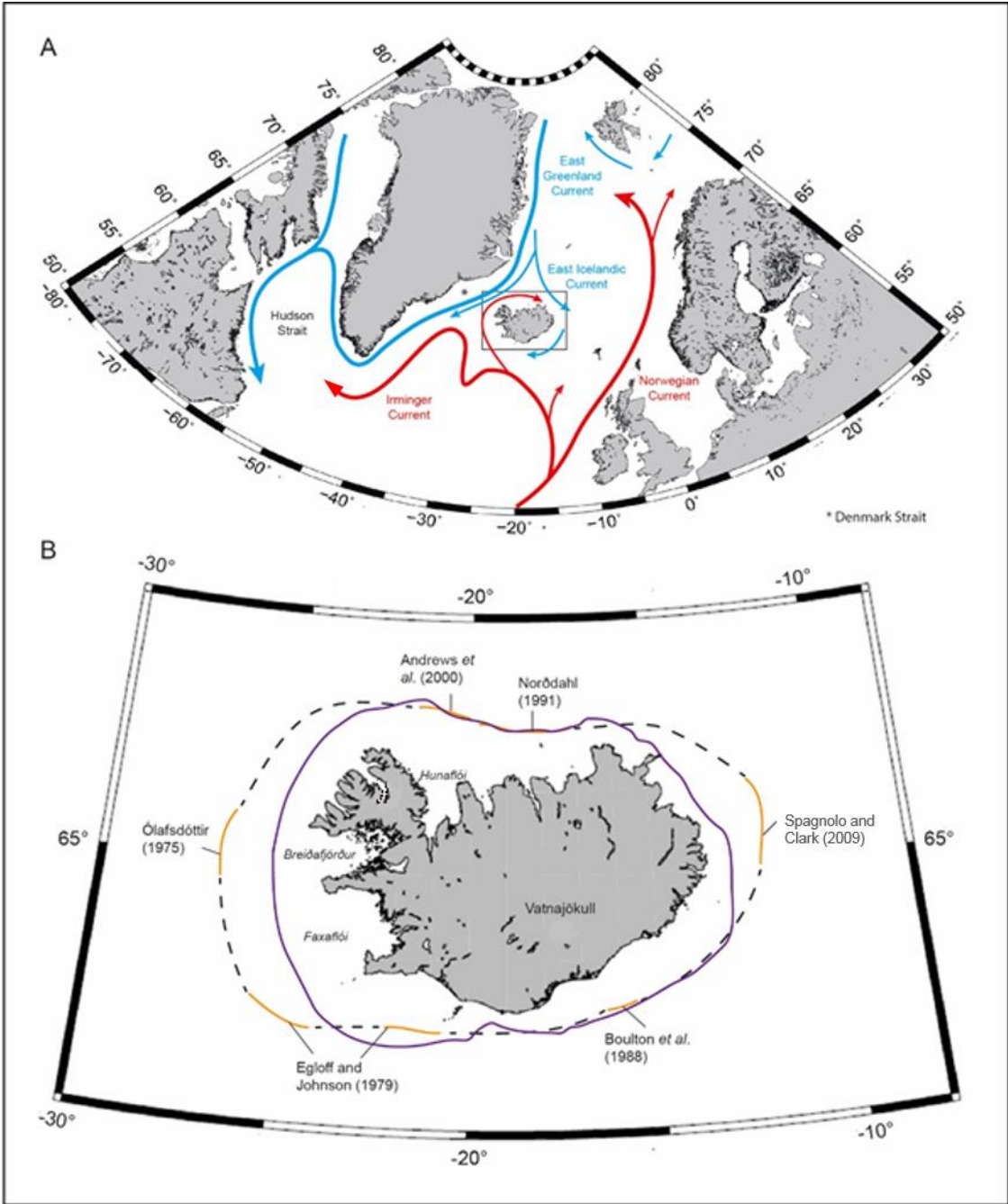
Postglacial relative sea-level changes in northwest Iceland: evidence from isolation basins, coastal lowlands and raised shorelines

1. Introduction

A range of evidence has been used to investigate the lateral and vertical extent of the Last Glacial Maximum (LGM) Icelandic Ice Sheet (IIS), including glacial geomorphology, striation mapping (e.g. Thorodssen, 1905-1906; Hoppe, 1968; 1982), sedimentology (e.g. Syvitski *et al.*, 1999; Andrews *et al.*, 2000), seismic profiling (Egloff and Johnson, 1979), submerged feature mapping (Spagnolo and Clark, 2009), ice sheet modelling (Hubbard *et al.*, 2006; Hubbard, 2006), marine limit mapping (Norðdahl and Pétursson, 2005; Norðdahl *et al.*, 2008), and ocean coring (Andrews *et al.*, 2000; Eiríksson *et al.* 2000). However, none of these methods have been able to unequivocally determine the most likely LGM ice loading scenario for Iceland. Relative sea-level studies have the potential to produce high-resolution data to identify the location and thickness of former ice loading through constraint of the marine limit, the establishment of deglacial timing and the patterns of Lateglacial to Holocene relative sea-level changes. In turn, these data act as important constraints for glacio-isostatic adjustment (GIA) models, which can further assist in the testing of ice loading hypotheses, lithospheric and mantle viscosity characteristics. This paper provides new relative sea level (RSL) data from northwest (NW) Iceland, which reflect post-(de)glacial loading and unloading of the crust as a result of near-equilibrium glacio-isostatic conditions during deglaciation (Norðdahl and Ingólfsson 2015). Establishing the lateral and vertical extents of the LGM IIS, associated ice volumes and patterns of deglaciation, is crucial, due to Iceland's location close to sensitive areas of deepwater formation in the Nordic Seas and northern North Atlantic (Dickson *et al.*, 2002; Fig. 1).

Isolation basins have been used in a number of locations close to present and former ice sheets to develop records of RSL change, including e.g. in Antarctica (Watcham *et al.*, 2011), Canada (Hutchinson *et al.*, 2004; Smith *et al.*, 2005), Finland (Eronen *et al.*, 2001), Greenland (Long *et al.*, 2011), Norway (Balascio *et al.*, 2011), Russia (Corner *et al.*, 1999), the UK (Shennan *et al.*, 1994; Shennan *et al.*, 1998) and Iceland (Rundgren *et al.*, 1997; Lloyd *et al.*, 2009). Isolation basins are rock depressions which have been connected to or isolated from the sea due to RSL changes across an impervious rock sill that controls tidal inundation (e.g. Lloyd and Evans, 2002, Long *et al.*, 2011). A series of stages of basin isolation have been identified (e.g. Lloyd and Evans, 2002) and analysis of sediment and microfossil datasets allows the identification of three isolation contacts – diatomological, hydrological and sedimentological - which can subsequently be linked to positions within the tidal frame (Kjemperud, 1986). Radiocarbon dates at these isolation contacts provide constraints on the timing of RSL change and the resulting RSL curves may in turn determine patterns of postglacial land-level change (e.g. Long *et al.*, 2011), allowing an assessment of former ice loading patterns.

73 Coastal lowlands are situated close to present sea-level and encompass the environment from
 74 mud flat to above high marsh conditions, and have the potential to record past RSL changes where
 75 sufficient accommodation space is available to record changes in environmental conditions.
 76 Coastal lowland environments may therefore encompass saltmarshes, which have previously been
 77 used in Iceland to reconstruct patterns of RSL change (e.g. Gehrels *et al.*, 2006; Saher *et al.*,
 78 2015).



79
 80 *Figure 1: A: Current oceanic circulation patterns in the North Atlantic, highlighting Iceland's position close to*
 81 *several major currents. B: Field and modelling evidence for the lateral extent of the LGM IIS, including*
 82 *undated moraines (solid orange), diverse physical evidence (black dashed, Norðdahl and Pétursson, 2005,*
 83 *Norðdahl and Ingólfsson, 2015) and modelled extent (solid purple, Hubbard et al., 2006).*

84 In this study, 16 new sea-level index points (SLIPs) are presented, based on diatomological,
85 tephrochronological and radiocarbon analyses on isolation basin and coastal lowland sediments,
86 which are combined with new and existing data derived from geomorphological indicators. The
87 resulting new RSL curves allow an assessment of the spatial variability of former RSL in NW
88 Iceland and thus the patterns of Lateglacial to Holocene ice loading in the region.

89 **2. RSL change in Iceland**

90 Until recently, RSL research in Iceland focussed on the investigation of the marine limit, which has
91 been extensively surveyed (e.g. Ingólfsson, 1991; Norðdahl and Pétursson, 2005; Norðdahl *et al.*,
92 2008). The marine limit is a raised shoreline which represents the highest point reached by post-
93 deglacial RSL (Andrews, 1970) and thus varies in age and elevation due to differences in ice
94 thickness and the style and timing of deglaciation (Ingólfsson, 1991; Jennings *et al.*, 2000;
95 Norðdahl and Ingólfsson, 2015). However, difficulties in determining the age of the marine limit in
96 Iceland have been noted, which is key if marine limit records are to be employed as robust
97 reconstructions of former RSL. In addition, marine limit datasets tend to produce single SLIPs,
98 which are of limited value as constraints for glacio-isostatic adjustment models. Isolation basin
99 studies have therefore provided additional constraints on proposed postglacial RSL changes in
100 Iceland (Norðdahl and Pétursson, 2005; Pétursson *et al.*, 2015). In the majority of cases, the
101 principal benefit of isolation basin studies is the provision of a complete RSL curve for a location,
102 which provides information regarding the tendency of RSL change, compared to individual SLIPs
103 from raised shorelines. These records of RSL changes are particularly important as a test for
104 glacio-isostatic adjustment (GIA) model outputs when exploring various ice loading scenarios (e.g.
105 Hubbard *et al.*, 2006; Patton *et al.*, 2017).

106 Mapping of the marine limit has identified that the highest marine limits are present at Akrafjall and
107 Stóri-Sandhóll, western Iceland, at 105 and 148 m a.s.l. (Ingólfsson and Norðdahl, 2001). Dating
108 at Stóri-Sandhóll has revealed an age of $12,928 \pm 95$ ^{14}C a BP (uncalibrated; Ingólfsson and
109 Norðdahl, 2001) or 14.7 cal. ka BP (Norðdahl and Ingólfsson, 2015). The high marine limit
110 elevations in western Iceland are taken as evidence for rapid deglaciation (Ingólfsson and
111 Norðdahl, 2001; Norðdahl and Ingólfsson, 2015). The pattern of marine limit elevation in NW
112 Iceland is particularly complex, ranging from 14 m a.s.l. in northern Vestfirðir (Principato, 2008) to
113 85 and 95 m a.s.l. in the Breiðavík-Látrar area in the southwesternmost part of Vestfirðir (Norðdahl
114 and Pétursson, 2005, Fig. 2).

115 Based on the existing data on raised marine shorelines in Iceland, Norðdahl and Pétursson (2005)
116 were able to depict a pair of distinct and younger shorelines below the marine limit shoreline, dated
117 to about 12.0 and 11.2 cal ka BP respectively, and both preceded by an increase in RSL (Norðdahl
118 and Pétursson 2005; Pétursson *et al.* 2015). A number of lower-elevation raised shorelines have
119 also been identified in Iceland, including the *Nucella* beach, which is characterised by '*Nucella*'

120 shell deposits at ~4-5 m a.s.l. (Bárðarson, 1906, 1910a, 1910b). An estimated age for the
121 formation of the '*Nucella* beach' in Hrótafjörður is ca. 4.5 cal. ka BP (Þórarinnsson, 1956; John,
122 1974; John and Alexander, 1975; Hansom and Briggs, 1991), whereas Eiríksson *et al.* (1998)
123 estimated its formation between ca. 3.2 and 5.7 cal. ka BP. In northern Vestfirðir, Principato (2008)
124 suggested an age of ca. 3 cal. ka BP for the 5 m beach and in southern Iceland Símonarson and
125 Leifsdóttir (2002) dated the 6 m beach there between 2.3 and 2.9 cal. ka BP (original dates; $2625 \pm$
126 40 and 3145 ± 35 ^{14}C a BP). These dates provide constraints on late Holocene RSL change in
127 Iceland.

128 More recently, isolation basin studies have been completed in Iceland to produce comprehensive
129 records of postglacial RSL changes (Rundgren *et al.*, 1997; Lloyd *et al.*, 2009; Brader *et al.*, 2015).
130 The first isolation basin study was undertaken on the Skagi peninsula (Rundgren *et al.*, 1997),
131 where a fall in RSL of 45 m between 13 cal. ka BP and 10.2 cal. ka BP is reported, during which
132 there were two marine transgressions of around 5 m amplitude up to Younger Dryas and Preboreal
133 shorelines. Isolation basin and raised shoreline evidence in southern Vestfirðir (Lloyd *et al.*, 2009)
134 and northern Snæfellsnes (Brader *et al.*, 2015) have provided an insight into RSL changes on the
135 northern and southern shorelines of Breiðafjörður, western Iceland. Lloyd *et al.* (2009) identified
136 the local marine limit at 80 m a.s.l. (with raised shorelines between 84 and 98 m a.s.l.) and
137 demonstrated a continuous RSL fall from ca. 14 cal. ka BP (estimated date from highest basin,
138 $12,185 \pm 100$ ^{14}C a BP) to the early Holocene in southern Vestfirðir. Initial rates of RSL fall were
139 high with a notable reduction in the rate of RSL fall during this period (Lloyd *et al.*, 2009), with an
140 intermediate elevation shoreline between 41 and 51 m a.s.l. dated to between 11.1 and 13.2 cal.
141 ka BP. Lloyd *et al.* (2009) highlight the potential for a RSL rise during the Younger Dryas in
142 southern Vestfirðir, although additional data are required to further test this hypothesis. An
143 increase in RSL in Allerød/Younger Dryas times has been demonstrated in other parts of Iceland
144 (Rundgren *et al.*, 1997; Norðdahl and Pétursson, 2005; Norðdahl and Ingólfsson, 2015). Lloyd *et*
145 *al.* (2009) also provide the first isolation basin evidence for a late-Holocene highstand in Iceland,
146 which has been seen elsewhere through '*Nucella* beach' deposits.

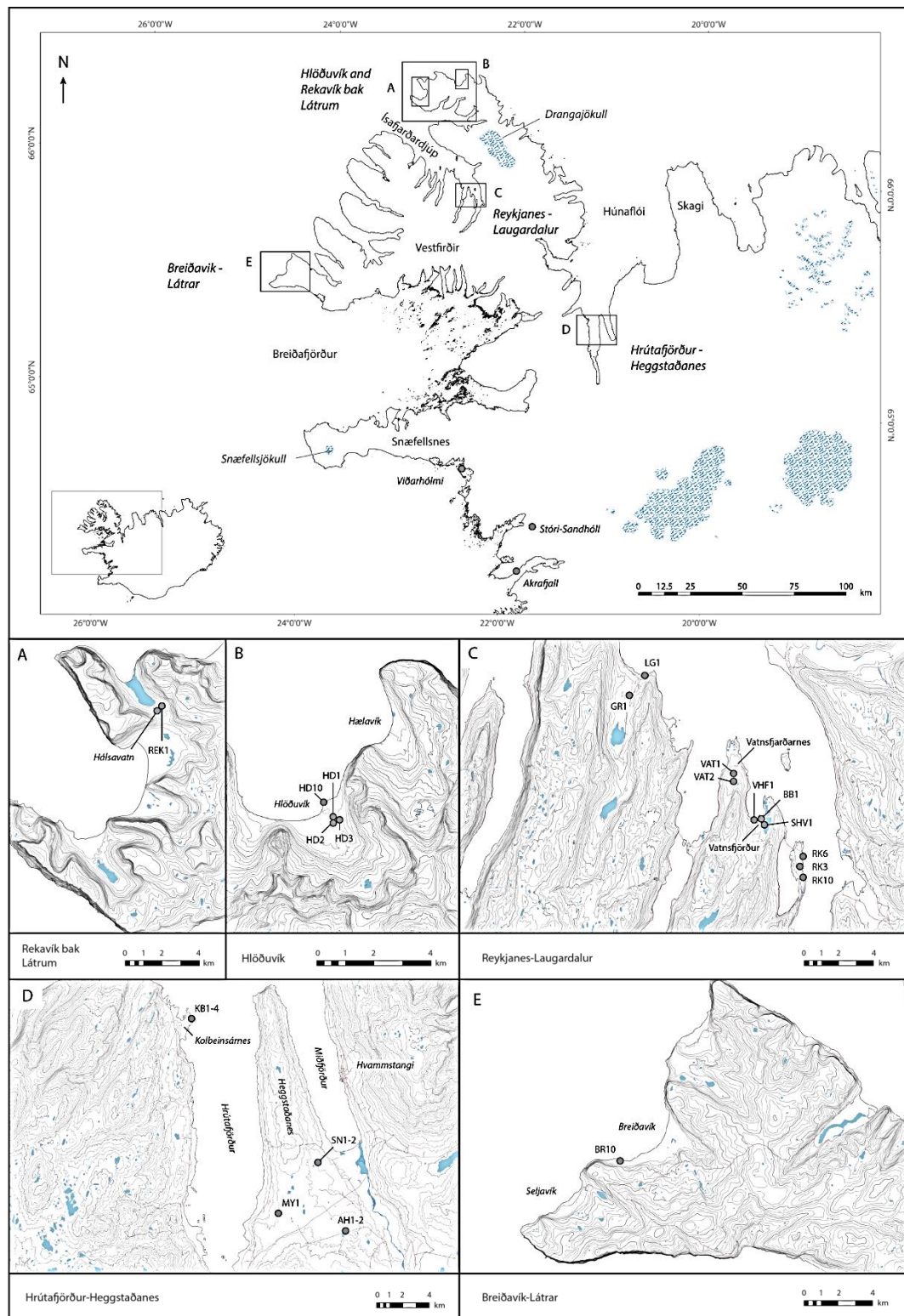
147 In contrast to southern Vestfirðir, the marine limit in northern Snæfellsnes is identified as 65 – 69 m
148 a.s.l. and limited influence of Younger Dryas ice re-advance is evident within the RSL record there
149 (Brader *et al.*, 2015). In Snæfellsnes, RSL fell below present sea level at ca. 10 cal. ka BP,
150 occurring a few centuries later than in south west Iceland (>10.5 cal. ka BP; Ingólfsson *et al.*, 1995)
151 and Skagi (>10.2 cal. ka BP; Rundgren *et al.*, 1997). There is however a clear contrast in the
152 patterns of RSL changes over relatively short distances within the region, likely as a consequence
153 of differences in lithospheric characteristics, the area available for ice accumulation, pattern and
154 style of deglaciation and age of the elevated shorelines (Ingólfsson and Norðdahl, 2001; Norðdahl
155 and Pétursson, 2005; Brader *et al.*, 2015; Norðdahl and Ingólfsson, 2015).

156 Late Holocene saltmarsh studies have been undertaken at Viðarhólmi, Snæfellsnes, western
157 Iceland in order to investigate more recent RSL changes (Gehrels *et al.*, 2006; Saher *et al.*, 2015).
158 The diatom record from Viðarhólmi highlights variability in the patterns of recent RSL changes,
159 possibly as a result of changes in the North Atlantic Oscillation (NAO; Saher *et al.*, 2015). Deeper
160 coring at the site also generated a series of basal SLIPs for the late Holocene (Gehrels *et al.*,
161 2006).

162 In addition to terrestrial records of RSL change, additional research has been undertaken using
163 marine records to constrain the RSL fall below present sea level in the early Holocene, including
164 seismic profiling (e.g. Thors and Boulton, 1991), records of submerged peat (e.g. Ingólfsson *et al.*,
165 1995) and marine core analysis (e.g. Quillman *et al.*, 2010). At present, there remains uncertainty
166 over the scale of the proposed early Holocene RSL lowstand, due to methodological limitations,
167 conflicts between evidence from different sources and poor spatial coverage. It is important to
168 establish the timing and magnitude of any RSL lowstand, as data constraining RSL change will be
169 important for the testing of GIA models in Iceland. New data from marine environments, which
170 could be combined with the new terrestrial evidence from isolation basins, coastal lowlands and
171 raised shorelines, would better constrain this RSL lowstand and in turn allow further testing of
172 contrasting uplift scenarios.

173 **3. Study area**

174 The present study is based on data collected from a number of locations on the Vestfirðir
175 Peninsula (NW Iceland) (Fig. 2). South of the study area is the Snæfellsnes Peninsula, which is
176 dominated by the ice-capped Snæfellsjökull Volcanic System and forms the southern coastline of
177 Breiðafjörður. East of the study area is the Skagi Peninsula, a large peninsula in North Iceland
178 characterized by a number of lake basins at its northernmost point (Rundgren *et al.*, 1997). The
179 peninsula forms the eastern coastline of Húnaflói, a major fjord system in North Iceland.
180 Drangajökull glacier is situated in northern Vestfirðir. The research locations explored within this
181 study are situated on the Vestfirðir Peninsula: Hlöðuvík and Rekavík bak Látrum (5 sites);
182 Reykjanes-Laugardalur in Ísafjarðardjúp (10 sites); and Breiðavík-Látrar (1 site; Fig. 2).
183 Hrótafjörður-Heggstaðanes forms the southeasternmost section of the study area (8 sites; Fig. 2).



184

185 *Figure 2: Study area in NW Iceland, highlighting the key research locations – A: Rekavík bak Látrum, B-*
 186 *Hlíðuvík, C - Reykjanes-Laugardalur, D – Hrútafjörður-Heggstaðanes, E – Breiðavík-Látrar - and sites*
 187 *mentioned in the text. Blue hashed areas – current glaciers, light blue – lakes. Base Map – Based on data*
 188 *from National Land Survey of Iceland.*

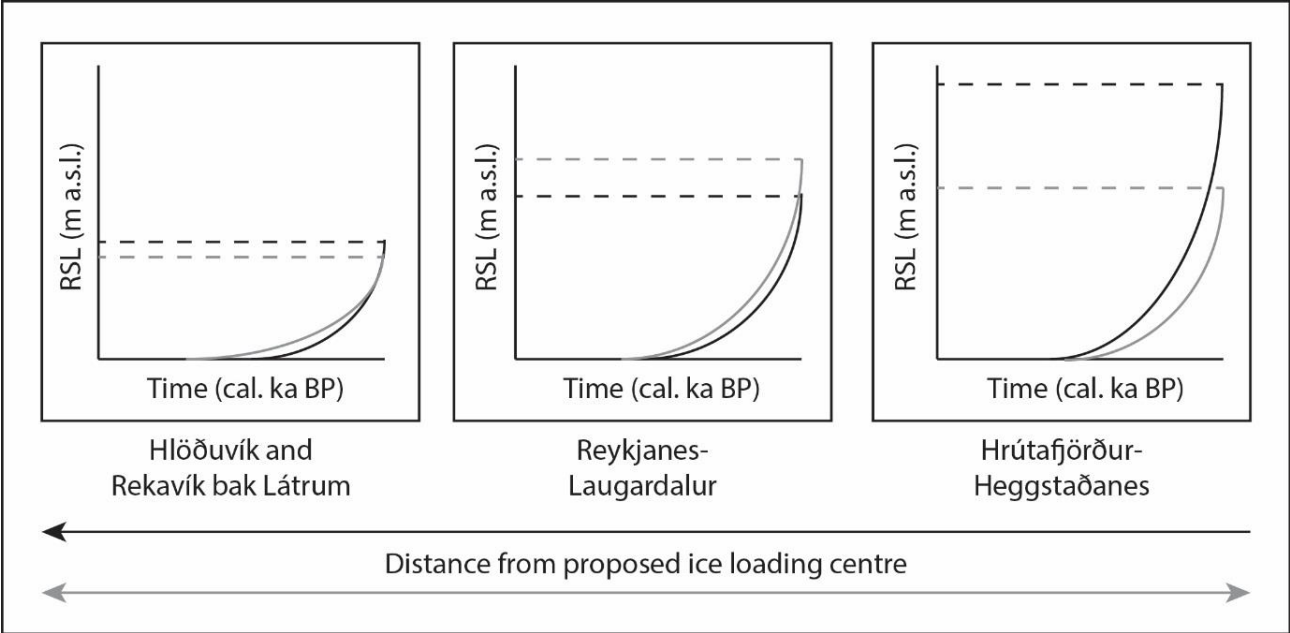
189 4. Methods

190

191 4.1 Site Selection

192 The sites were chosen to exploit RSL changes across a potential former ice loading centre above
 193 Vestfirðir. The sites in Hlöðuvík and Rekavík bak Látrum, Reykjanes-Laugardalur and Hrótafjörður-
 194 Heggstaðanes form the research transect, with secondary sites at Breiðavík and Látrar at the
 195 mouth of Breiðafjörður.

196 Figure 3 illustrates the hypothesised patterns of RSL change at the three main sites along the
 197 transect under two glacio-isostatic uplift scenarios. Under a regional uplift scenario, with ice
 198 loading emanating from central Iceland (black line, Fig. 3), it is proposed that the marine limit
 199 elevation would increase with proximity to the former centre of unloading (and therefore uplift) in
 200 central Iceland. Alternatively, the highest marine limit elevation would be found in Reykjanes-
 201 Laugardalur under a local uplift scenario (grey dashed line, Fig. 3), due to a centre of localised ice
 202 unloading in NW Iceland.



203
 204
 205 *Figure 3: Hypothesised patterns of RSL change if the centre of uplift was situated in central Iceland or if*
 206 *there was a local centre of uplift in central Vestfirðir in each of the principal research locations – Hlöðuvík*
 207 *and Rekavík bak Látrum, Reykjanes-Laugardalur, and Hrótafjörður-Heggstaðanes – in northwestern Iceland.*
 208 *Under the central Iceland scenario (black), distance from the loading centre increases leftward, whereas*
 209 *distance from the loading centre increases away from Reykjanes-Laugardalur under the local scenario (grey*
 210 *dash). The hypothesized marine limit is denoted by the dashed lines.*

211 4.2 RSL reconstruction

212 In order to assess patterns of RSL change in NW Iceland, we collected isolation basin and coastal
 213 lowland sediment samples from the marine limit to present sea level in each of the four field
 214 locations. The isolation basins were selected using the criteria outlined by Long *et al.* (2011),
 215 ensuring a suitable size (<1 km²), depth (<10 m) and spacing of sites in each research location
 216 (see Long *et al.* (2011) for further information). Where the basin sill was covered by overlying

217 sediments, a grid of cores established the lowest high point in the underlying bedrock. The
218 elevation of the isolation basin sill was measured relative to mean high water spring tide (MHWST)
219 in the field using an Electronic Distance Meter (EDM; ± 0.1 m) and subsequently corrected to mean
220 sea level (MSL or m a.s.l.) using tide tables for the nearest tide station (Admiralty Tide Tables,
221 2006).

222 The stratigraphy of each isolation basin was established by coring perpendicular transects with a
223 gouge corer from infilled sections or from the rear of a boat when a lake was present. Samples
224 extracted were described using the Troels-Smith (1955) classification scheme. Following initial
225 survey, a core was extracted from the deepest point along the transect using a Russian corer
226 (Jowsey, 1966).

227 Diatom preparation followed the standard procedures outlined by Palmer and Abbott (1986) and
228 diatoms were classified using a range of sources (e.g. Brun, 1965; Foged, 1974; Hartley, 1996). A
229 minimum of 300 diatoms were counted per sample and subsequently grouped by halobian
230 classification (Hustedt, 1957) as follows: polyhalobian (marine), mesohalobian (brackish),
231 halophilous (salt tolerant), oligohalobous – indifferent (freshwater) and halophobous (salt
232 intolerant). Summary diatom figures are given in the main text with full diatom assemblage graphs
233 provided within Supplementary Information. Diatom zones are based on changes in taxa
234 composition within individual assemblages. Microfossil analyses of isolation basin sediment
235 sequences can allow the identification of three isolation contacts - the diatomological, hydrological
236 and sedimentological contacts (Kjemperud, 1986) - which can be related to key positions within the
237 tidal frame. Mean High Water Spring Tide (MHWST) is frequently used for the diatomological
238 isolation contact (Long *et al.*, 2011), which is characterised by predominantly freshwater conditions
239 with a minor brackish element. The hydrological isolation contact represents entirely freshwater
240 conditions and equates to Highest Astronomical Tide (HAT).

241 Chronological control of isolation contacts was established with a combination of radiocarbon and
242 tephra analyses. Due to a lack of macrofossil material, the accelerator mass spectroscopy (AMS)
243 radiocarbon dates were based on bulk organic sediment samples in close proximity to the isolation
244 contact and were analysed at the NERC Radiocarbon Facility (NRCF). Tephra samples were
245 analysed at the Tephra Analytical Unit, School of GeoSciences, University of Edinburgh using a
246 Cameca SX100 electron microprobe. Details of the tephra analytical conditions can be found in
247 Supplementary Information. Both radiocarbon and tephra samples underwent an acid pre-
248 treatment prior to analysis. Radiocarbon dates are calibrated with the Radiocarbon Calibration
249 Program (CALIB) Rev. 7.1 html (Stuiver and Reimer, 1993) with the IntCal13 data set for terrestrial
250 material (Reimer *et al.*, 2013).

251 In order to establish the elevation of former RSL, a correction is required based on the indicative
252 meaning of the dated point in the diatom assemblage (see Shennan *et al.*, 2015), with the error
253 comprised of elevation uncertainty, sill determination uncertainty and the indicative range of the

254 assemblage. Establishment of a series of SLIPs for each research location has allowed the
255 production of a series of new RSL curves for NW Iceland. Full details of site stratigraphies, diatom
256 assemblages and tephra geochemical results are presented as Supplementary Information.

257 **5. Results - New sea-level index points for NW Iceland**

258 Results of stratigraphic, diatom and chronological analyses are divided into the four principal
259 geographical locations investigated as part of this research (Fig. 2). In total, 16 new SLIPs and 4
260 limiting points have been generated for NW Iceland.

261 *5.1 Hlöðuvík and Rekavík bak Látrum (Area A and B (Fig 2); five sites)*

262 Four lake basins and one raised shoreline were surveyed in Rekavík bak Látrum and Hlöðuvík
263 (Fig. 2A and B). The majority of these sites are found in Hlöðuvík, where the marine limit can be
264 traced across the mouth of the valley at about 15 m a.s.l. and at ~ 26 m a.s.l. in nearby Hælavík
265 (Hjort *et al.*, 1985). One basin was also surveyed in Rekavík bak Látrum, close to the local marine
266 limit at 15-25 m a.s.l. (Hjort *et al.*, 1985). Sections 5.1.1 to 5.1.5 provide an overview of the
267 stratigraphy and diatom assemblage for each site, with information for each location summarised in
268 Fig. 4.

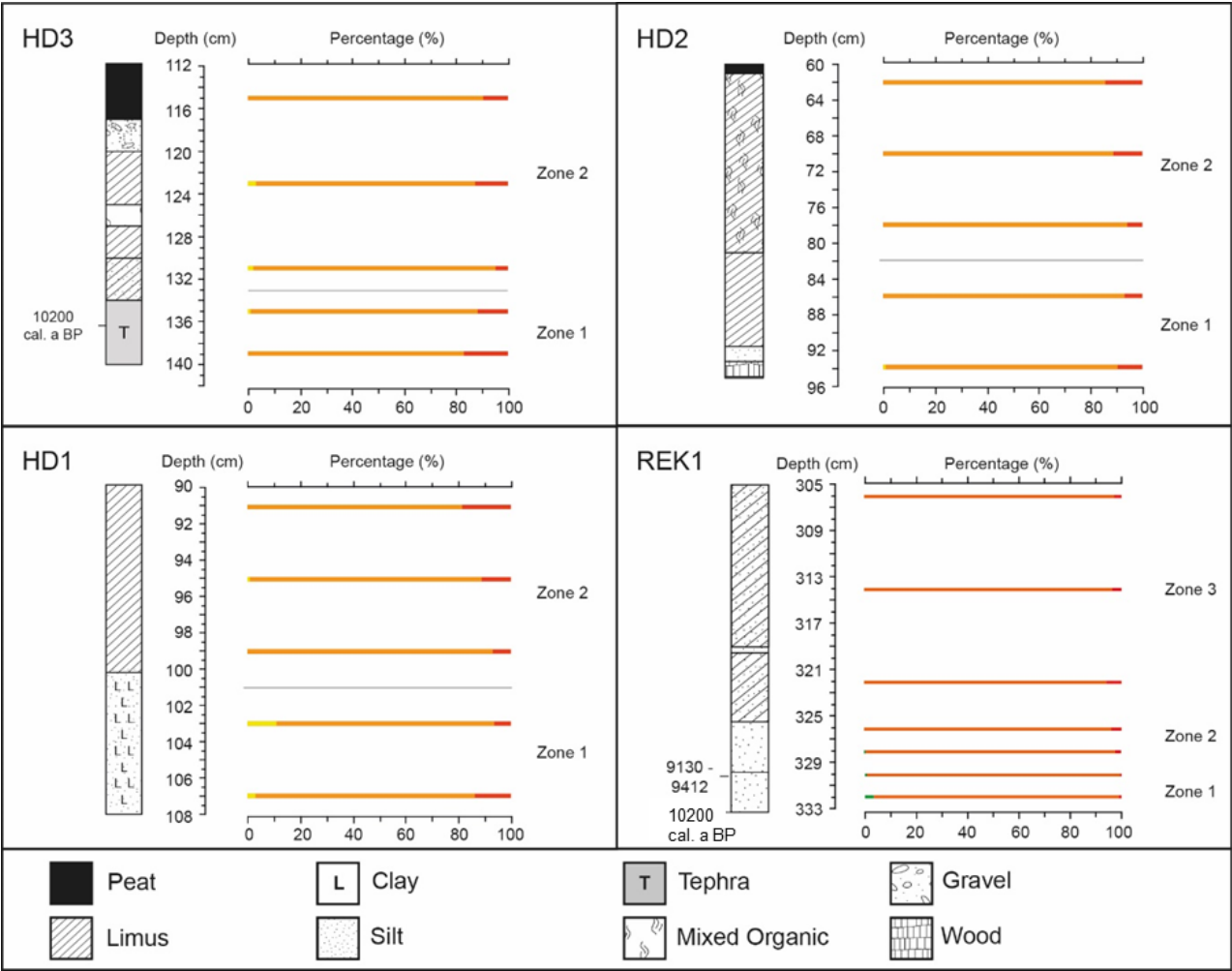
269 5.1.1 Hlöðuvík 3 (HD3) - 66°24.965' N, 22°38.857' W - Sill Elevation: 18.01 ± 0.30 m a.s.l.

270 HD3 is the lowest basin sampled in Hlöðuvík (Fig. 2B). The stratigraphy is characterised by a
271 basal tephra deposit overlain by olive green limus, sandy gravel and uppermost turfa peat, with a
272 visible tephra at the base of the analysed core (Fig. 4). Geochemical analysis of a dark grey/black
273 tephra deposit allows identification as being part of the Saksunarvatn sequence of tephras (Fig. 5).
274 It is now apparent that there were multiple eruptions of Grímsvötn between 9.9 cal ka BP and 10.4
275 cal ka BP (Jennings *et al.*, 2014), with up to 7 eruptions responsible for tephra deposits heading
276 north and west of Grímsvötn onto the north Iceland and SE Greenland shelves. Three of these
277 have major element characteristics which are indistinguishable from the Saksunarvatn tephra
278 dated to approximately 10.2 ka (Jennings *et al.*, 2014; Lohne *et al.*, 2014). The oldest and thickest
279 of these has been dated to around 10380 cal BP (10284–10501 cal BP) by Kristjánsdóttir *et al.*
280 (2007) and Jennings *et al.* (2014) suggest that a correlation to the 10252-10342 cal BP ice-core
281 dated 'Saksunarvatn' tephra (Rasmussen *et al.*, 2007) is likely, but cannot be confirmed. It is likely
282 that the 'Saksunarvatn' tephra found in our cores correlates with this too, but again cannot be
283 confirmed. Diatom analysis shows freshwater conditions dominate at the site, suggesting that RSL
284 was lower than the sill elevation at 10.2 cal. ka BP. This also acts as a limiting age for marine limit
285 formation.

286 5.1.2 Hlöðuvík 2 (HD2) - 66°25.156' N, 22°38.846' W – Sill Elevation: 18.13 ± 0.30 m a.s.l.

287 HD2 is a small basin situated west of HD3 (Fig. 2B). The site stratigraphy is comprised of a basal
288 silt, overlain by olive-green limus and turfa peats. No tephra deposits were found at the site. The

289 diatom assemblage for HD2 is dominated by freshwater conditions (Fig. 4) suggesting that the site
 290 was situated above the influence of marine conditions and thus the site acts as a limiting elevation
 291 for postglacial RSL at the location.



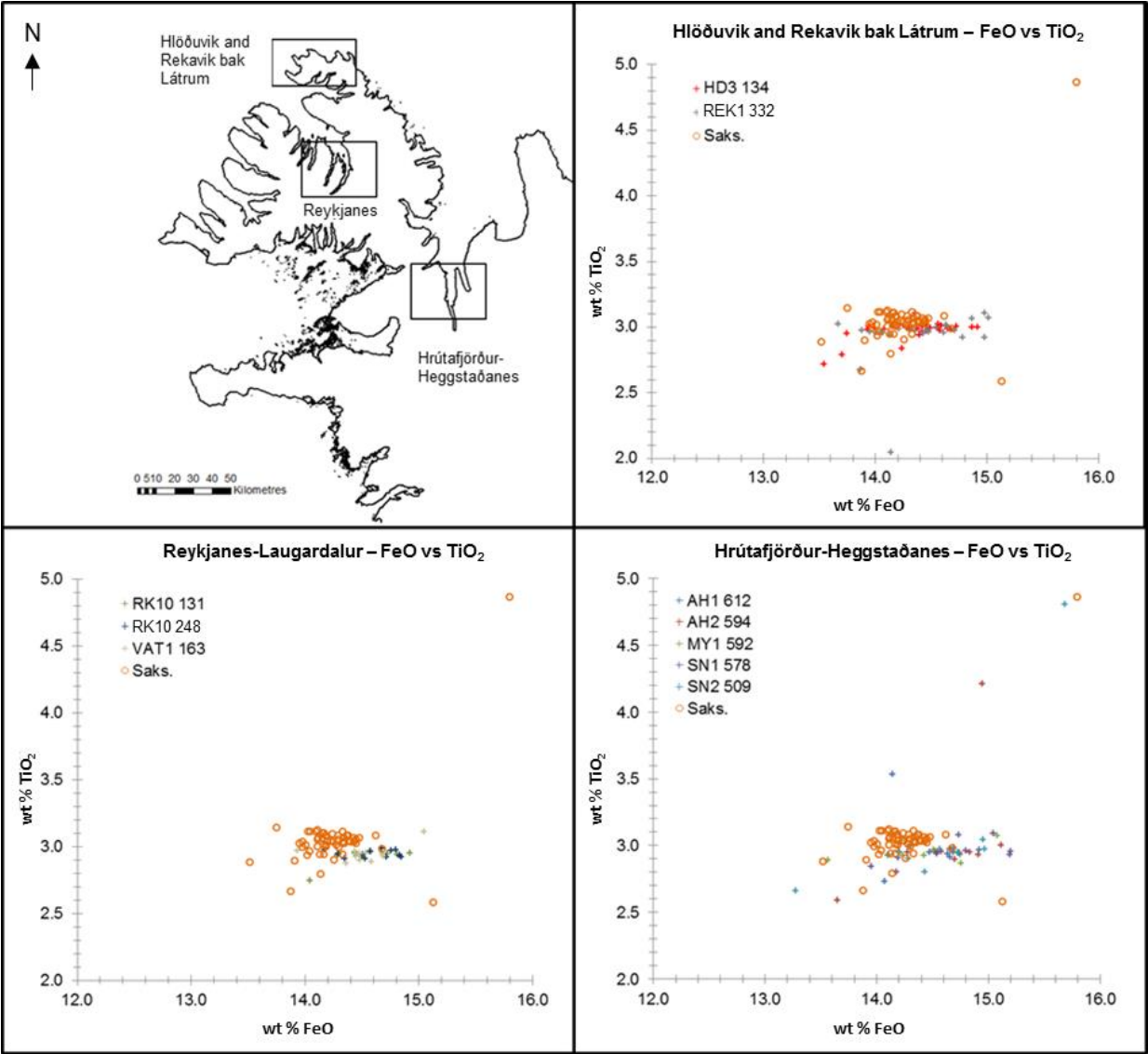
293 *Figure 4: Summary diatom assemblages and stratigraphic profiles for sites in Hlöðuvík and Rekavík bak*
 294 *Látrum showing the key environmental changes recorded in each location: HD3 – Hlöðuvík 3, HD2 –*
 295 *Hlöðuvík 2, HD1 – Hlöðuvík 1 and REK1 – Rekavík bak Látrum 1. Diatoms are grouped by salinity: blue –*
 296 *marine, green – brackish, yellow – salt tolerant, orange – freshwater, red – salt intolerant. Full diatom*
 297 *assemblages and core stratigraphies are provided in Supplementary Information.*

298 5.1.3 Hlöðuvík 1 (HD1) - 66°25.142' N, 22°38.776' W – Sill Elevation: 18.71 ± 0.30 m a.s.l.

299 HD1 is a small but the uppermost basin in Hlöðuvík (Fig. 2B). The site stratigraphy is
 300 characterised by a basal blue-grey clay overlain by olive-green limus. Above this layer, an organic
 301 rich layer is evident, covered by turfa peat. The diatom assemblage is dominated by freshwater
 302 taxa (Fig. 4) and therefore the site acts as a limiting elevation for former RSL.

303 5.1.4 Hlöðuvík Raised Shoreline (HD10) - 66°25.354' N, 22°38.857' W – Sill Elevation: 17.48 ±
 304 1.00 m a.s.l.

305 The raised shoreline in Hlöðuvík was surveyed using an EDM in order to establish the highest
 306 postglacial RSL in the region (Fig. 2B). Surveying established the minimum elevation of the
 307 marine limit at ~18 m a.s.l., just above the value reported by Hjort *et al.* (1985, 10-15 m a.s.l.). The
 308 raised beach is characterised by a lower till deposit, overlain by marine sediments, with a
 309 subsequent upper till. There was a lack of dateable material within the proposed 'marine'
 310 sediments, meaning that it has not been possible to establish an accurate chronology for this
 311 feature. However, the discovery of the Saksunarvatn tephra (10.2 cal. ka BP) in the basins above
 312 the marine limit acts as a limiting age for feature formation.



313
 314 *Figure 5: Geochemical results of tephra analyses on samples from Hlöðuvík and Rekavík bak Látrum,*
 315 *Reykjanes-Laugardalur and Hrótafjörður-Heggstaðanes. Samples are plotted against Saksunarvatn*
 316 *geochemistries (orange circles) sourced from TephraBase (2015).*

317 5.1.5 Rekavík bak Látrum (REK1) - 66°24.500' N, 23°0.441' W – Sill Elevation: 18.63 ± 0.30 m
 318 a.s.l.

REK1 is situated aside a kettle-hole lake (Hálsavatn) in Rekavík bak Látrum and represents the westernmost field site in the region (Fig. 2A). The site stratigraphy is comprised of a basal tephra-rich gravel overlain by clay rich silts, silty limus and an uppermost organic rich limus (Fig. 4). The Saksunarvatn tephra was identified at the base of the core following geochemical analysis of a black tephra deposit (10.2 cal. ka BP; Fig. 5). There is a clear dominance of freshwater conditions at the site, but the occurrence of limited numbers of brackish taxa suggests occasional inundation by highest times or storm events at the base of the core. A radiocarbon sample at 330 cm produced an age of isolation of 9130 – 9412 (9.2 k) cal. a BP (Table 1), which provides a limiting (minimum) age for marine limit formation in the region.

5.1.6 RSL curve for Hlöðuvík and Rekavík bak Látrum

The results from Hlöðuvík and Rekavík bak Látrum provide one new SLIP and one limiting point for postglacial RSL in the region (Table 1; Fig. 6). Due to the geomorphology of the region, there are limited locations with sufficient coastal lowlands to produce a large number of SLIPs. However, these new data provide valuable constraint on RSL change for the location, which is situated at the northwesternmost point of the principal research transect.

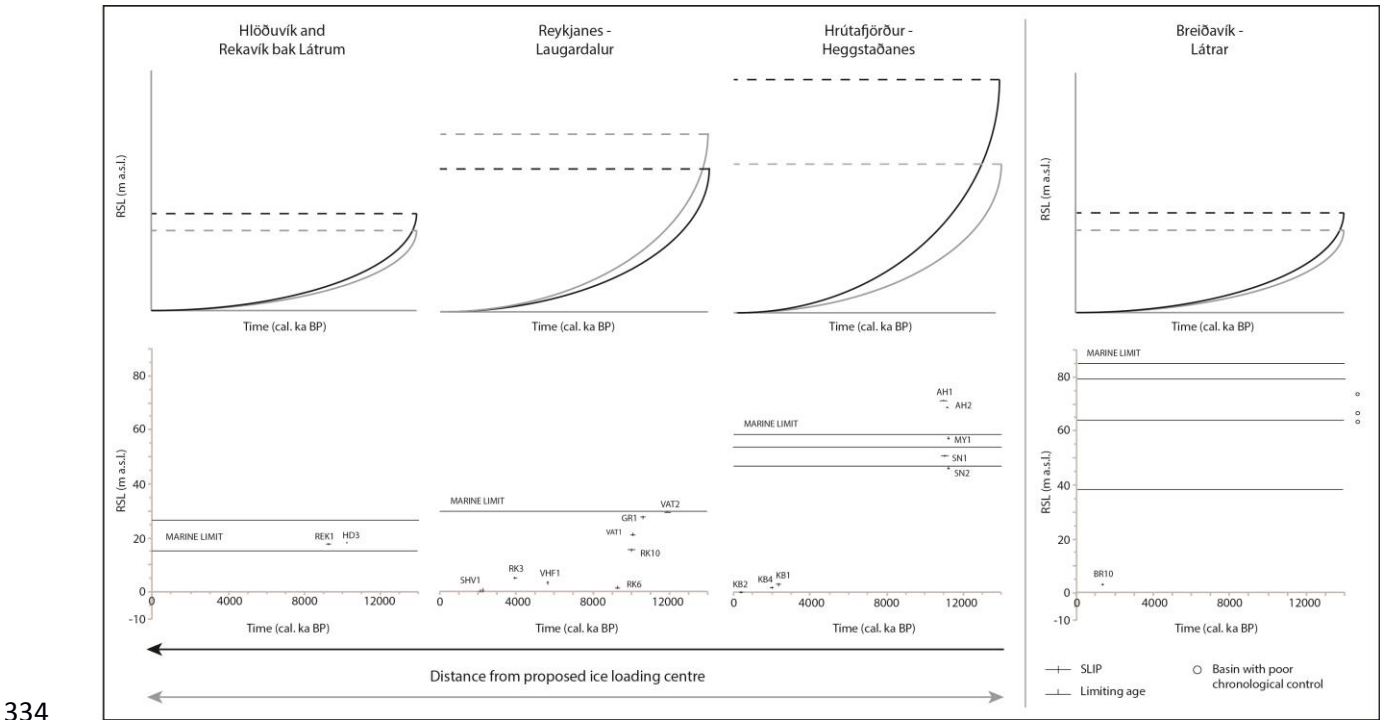


Figure 6: Hypothesised and reconstructed RSL curves for NW Iceland, based on new and existing data from the region. Hypothesised RSL curves are based on Figure 3, with grey representing localised uplift and black representing the central uplift scenario. The hypothesised RSL curve for Breiðavík-Látrar is based on its position at an extreme terrestrial location from the principal uplift centre in central Iceland. Reconstructed RSL curves are plotted along the principal research transect in NW Iceland - Hlöðuvík and Rekavík bak Látrum (NW), Reykjanes-Laugardalur (central) and Hrótafjörður-Heggstaðanes (SE) - with Breiðavík-Látrar (SW) plotted separately.

342 5.2 Reykjanes-Laugardalur (Area C (Fig. 2); 10 sites)

343 Ten sites in the Reykjanes-Laugardalur area were investigated from the marine limit to present sea
344 level. Reykjanes-Laugardalur represents the centre-point for the research transect to evaluate
345 contrasting glacio-isostatic uplift scenarios due to different uplift centres (Fig. 3).

346 5.2.1 Bólvík (BB1) - 65°56.392' N, 22°29.029' W – Sample Elevation: -0.50 ± 0.25 m a.s.l.

347 BB1 is a small embayment close to the farm at Vatnsfjörður, (Fig. 2C). A sample comprising basal
348 gravel rich silt, overlain by a gravel rich turfa peat and uppermost gravel rich silt layer was collected
349 close to the present beach (Fig. 7). Diatom analysis reveals marine dominance in the lowermost
350 unit, with a limited (~20%) freshwater component to the diatom assemblage. Within the turfa peat,
351 freshwater influence increases with a minor brackish component. Diatom preservation in the
352 uppermost sediment unit was poor and provided insufficient numbers for a reliable sample for
353 analysis. A radiocarbon date from the turfa peat (bulk sample) returned a 'modern' age for the
354 deposit (Table 1).

355 5.2.2 Sveinhúsavatn (SHV1) - 65°56.210' N, 22°28.193' W – Sill Elevation: 1.24 ± 0.30 m a.s.l.

356 SHV1 is a relatively large lake basin close to the farm at Vatnsfjörður (Fig. 2C). The site
357 stratigraphy comprises sandy silts with distinct shell layers. The diatom assemblage can be
358 divided into eight distinct zones, showing the transition from brackish-marine to brackish-
359 freshwater dominance at the site, which is still connected to the sea at present. A series of tephra
360 layers are found through the sediment profile, which underwent geochemical analysis (Fig. 7;
361 Anderson, personal communication, 2016). The tephra layers at 270 cm, 215 cm and 165 cm
362 were identified respectively as the Landnám layer (the Settlement Layer) 877AD (1073 cal. a BP),
363 Eldgjá 939AD (1011 cal. a BP) (cf. Schmid *et al.*, 2016) and Hekla 1693AD (257 cal. a BP) tephra
364 (cf. Brynjólfsson *et al.* 2015). In addition, two radiocarbon samples were analysed from 218 cm
365 (1996 - 2299 (2.1 k) cal. a BP) and 228 cm (2158 – 2349 (2.25 k) cal. a BP), establishing a
366 chronology for the site. Two SLIPs were generated providing constraint on late Holocene RSL
367 changes in the region (Table 1).

368

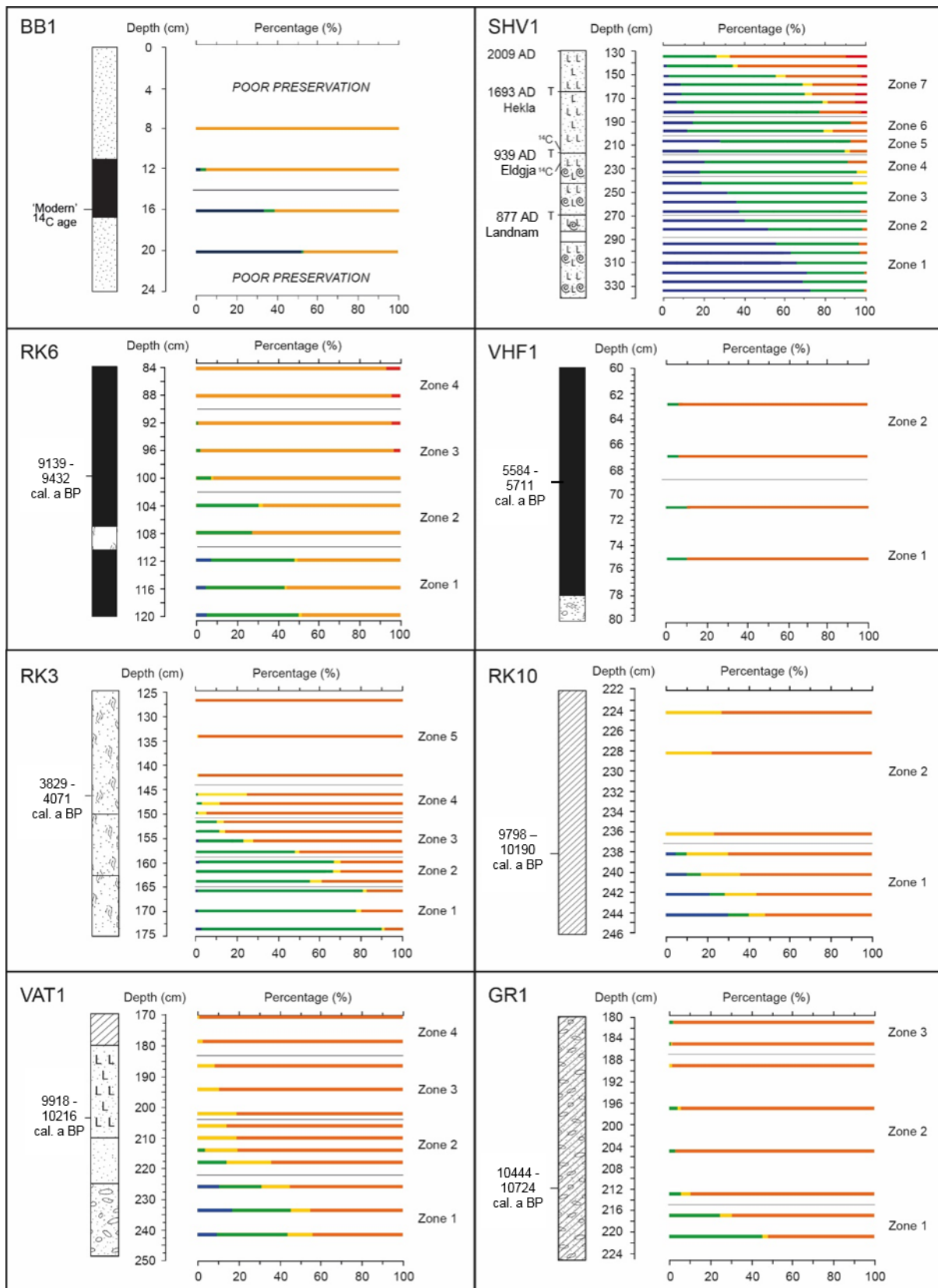
369 5.2.3 Reykjanes 6 (RK6) - 65°55.193' N, 22°25.588' W – Sill Elevation: 2.30 ± 0.30 m a.s.l.

370 RK6 is a small basin, found north of the present airfield on Reykjanes (Fig. 2C). The sediment
371 profile at RK6 comprises a basal olive green mixed organic material, overlain by a lower peat layer,
372 olive green humified organic material and middle peat layer. Above this, is an upper olive green
373 organic layer, overlain by an upper turfa peat layer. The diatomological isolation contact is
374 identified at 100 cm (Fig. 7) shown by a reduction in brackish conditions at the site. A bulk organic
375 radiocarbon sample at 100 cm produced an age for the SLIP of 9139 – 9432 (9.3 k) cal. a BP
376 (Table 1).

377 5.2.4 Vatnsfjörður Home Field (VHF1) - 65°56.324' N, 22°30.000' W – Sample Elevation: 4.50 ±
378 0.30 m a.s.l.

379 VHF1 is situated close to an archaeological site and present farm at Vatnsfjörður (Fig. 2C). The
380 stratigraphy is made up of a basal blue-grey sandy clay, overlain by extensive peats. A number of
381 sediment samples were extracted through the profile. Diatom analysis shows the core dominated
382 by freshwater conditions, with a weak brackish signal at the base (Fig. 7). A radiocarbon sample at
383 69 cm provides a marine limiting age of 5584 – 5711 (5.6 k) cal. a BP (Table 1).

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Figure 7: Summary diatom assemblages and stratigraphic profiles for sites in Reykjanes-Laugardalur showing the key environmental changes recorded in each location: BB1 – Bólvík, SHV1 – Sveinhúsavatn, RK6 – Reykjanes 6, VHF1 – Vatnsfjörður Home Field, RK3 – Reykjanes 3, RK10 – Reykjanes 10, VAT1 – Vatnsfjarðarháls 1, GR1 – Grímhólsvatn. For the key, refer to Figure 4.

391 5.2.5 Reykjanes 3 (RK3) - 65°54.171' N, 22°25.069' W – Sill Elevation: 6.19 ± 0.30 m a.s.l.

392 RK3 is situated between RK6 and RK10, south of the present airfield on Reykjanes (Fig. 2C). A
393 sediment sample comprised a basal brown silty mixed organic material, overlain by a grey silt,
394 brown mixed organic material and upper peat layer. The diatom assemblage shows a transitional
395 sequence and can be divided into five zones. A radiocarbon sample at 147 cm produced a timing
396 of isolation of 3829 – 4071 (3.9 k) cal. a BP (Fig. 7; Table 1). There is a clear reduction in marine
397 influence at the site over the course of the diatom record (Fig. 7).

398 5.2.6 Reykjanes 10 (RK10) - 65°54.321' N, 22°25.184' W – Sill Elevation: 16.49 ± 0.30 m a.s.l.

399 RK10 is a predominantly infilled basin on the Reykjanes peninsula, situated between RK3 and the
400 airfield (Fig. 2C). The site stratigraphy is characterised by a basal gravel, extensive limus deposits
401 and turfa peat. Diatom analysis highlights two distinct zones (Fig. 7). The diatomological isolation
402 contact is clearly evident at 237 cm and a bulk radiocarbon sample at 238 cm returned an age for
403 the SLIP of 9798 – 10190 (10.0 k) cal. a BP (Table 1). In addition, the Saksunarvatn tephra was
404 identified by geochemical analysis at 248 cm, providing a second (minimum) age of 10.2 cal. ka BP
405 (Fig. 5). There is a clear reduction in marine influence at the site, suggesting a RSL fall at the
406 location.

407 5.2.7 Vatnsfjarðarháls 1 (VAT1) - 65°57.823' N, 22°31.175' W – Sill Elevation: 22.22 ± 0.30 m
408 a.s.l.

409 VAT1 is situated at the head of the Vatnsfjarðarnes peninsula (Fig. 2C). The stratigraphy was
410 determined through a transect of 15 cores and comprises a basal gravel, grey silt, olive green
411 limus and upper turfa peat. An extensive tephra deposit is also evident at the site, occurring
412 shortly after the transition from silt to limus. Geochemical analysis of these dark grey deposits has
413 identified the Saksunarvatn tephra at 163 cm (10.2 cal. ka BP; Fig. 5). The diatom assemblage
414 from VAT1 can be divided into four distinct zones (Fig. 7). The diatomological isolation contact is
415 identified at 204 cm from which a radiocarbon sample produces an age of 9918 – 10216 (10.1 k)
416 cal a BP (Table 1) for the SLIP. Consequently, a weak marine phase is terminated at ca. 10.1 cal.
417 ka BP, with the Saksunarvatn tephra (10.2 cal. ka BP) found above the section.

418 5.2.8 Grímhólsvatn (GR1) - 66°0.053' N, 22°39.353' W – Sill elevation: 28.52 ± 0.30 m a.s.l.

419 GR1 is a large basin situated close to the local marine limit at ~25 m a.s.l. in Laugardalur (Fig. 2C).
420 The core from the northern section of the present lake basin is characterised by a basal silty brown
421 limus overlain by an olive green limus layer. The diatomological isolation contact is identified at
422 212 cm, with a radiocarbon sample generating an age of 10444 - 10724 (10.6 k) cal. a BP for the
423 SLIP indicating a reduction in marine influence of a brackish environment at the location (Fig. 7).

424 5.2.9 Vatnsfjarðarháls 2 (VAT2) - 65°57.553' N, 22°30.956' W – Sill Elevation: 29.59 ± 0.30 m
425 a.s.l.

VAT2 is a large basin found above and south of site VAT1 on the Vatnsfjarðarnes peninsula (Fig. 2C). The collected core was comprised of a basal gravel, overlain by silty clay, limus and peat layers. The diatom assemblage is dominated by freshwater conditions. There is a short-lived brackish component at 428 cm, which may represent a storm event or brief marine incursion of the basin. A clear transitional sequence is not evident at the site, suggesting that the site was situated above the influence of marine conditions. A radiocarbon sample at 428 cm produced an age of 11712 – 12067 (11.9 k) cal. a BP (Table 1) for a short-lived brackish episode.

5.2.10 Laugardalur (LG1)

The raised shoreline at Laugardalur provides an elevation for the local marine limit in Reykjanes-Laugardalur (Fig. 2C). The distinctive feature is found at the mouth of Laugardalur valley and was surveyed in a number of locations using an EDM to ~25/30 m a.s.l. A lack of dateable material means that it has not been possible to directly date the feature, although diatom analysis from GR1 provides a limiting age for formation of the shoreline.

5.2.11 RSL curve for Reykjanes-Laugardalur

Eight new SLIPs and the surveyed marine limit produce a new RSL curve for the region (Fig. 6; Table 1). The new RSL curve for Reykjanes-Laugardalur shows RSL rapidly falling from the marine limit at ~25/30 m a.s.l., which may have been formed at ca. 10.6 – 11.9 cal. ka BP, to below present sea level by ca. 9.3 cal. ka BP. RSL then rose above present sea level to a mid-Holocene highstand at ~4 m a.s.l. between ca. 4 and 5.8 cal. ka BP, before falling to present sea level (Fig. 6). The regression sequences from RK6 and VHF1 mean that sea-level must have risen to or close to the elevation of these sites during the early to mid- Holocene.

5.3 *Hrútafjörður-Heggstaðanes (Area D (Fig. 2); eight sites)*

Eight isolation basin and coastal lowland sites were investigated in the Hrútafjörður-Heggstaðanes area, which represents the innermost research location along the principal research transect through NW Iceland (Fig. 3).

5.3.1 Kolbeinsárnes 2 (KB2) - 65°25.978' N, 21°11.793' W – Sill Elevation: 1.09 ± 0.30 m a.s.l.

KB2 is a lake situated on the Kolbeinsárnes peninsula on the western coastline of Hrútafjörður (Fig. 2D) inundated at high tide. A core for analysis was extracted from the infilled section to the rear of the basin, summarised as a basal grey silt, subsequent blue-grey silty clays and an overlying *Sphagnum* peat layer. No tephra layers were evident at the site. Diatom analysis reveals a gradual transition from brackish-marine dominance to an increase in freshwater taxa presence (Fig. 8). A bulk radiocarbon sample at 30 cm provides an age of 308 – 484 (0.4 k) cal. a BP for the reduction of marine influence at the site and a known position within the tidal frame (ongoing isolation).

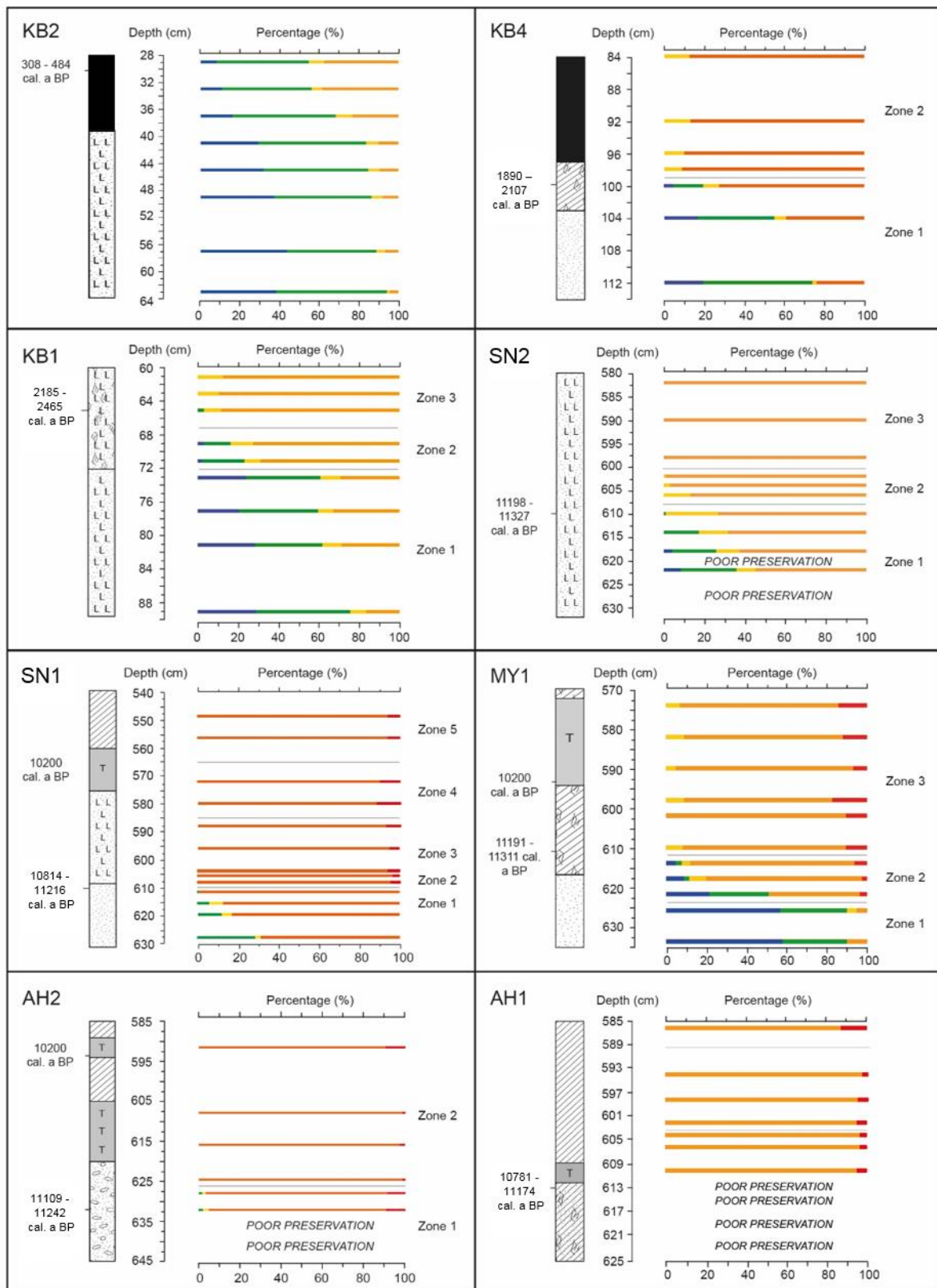


Figure 8: Summary diatom assemblages and stratigraphic profiles for sites in Hrútafjörður-Heggstaðanes showing the key environmental changes recorded in each location: KB2 – Kolbeinsárnes 2, KB4 – Kolbeinsárnes 4, KB1 – Kolbeinsárnes 1, SN2 – Sandavatn 2, SN1 – Sandavatn 1, MY1 – Mýrar 1, AH2 – Álfhóll 2, AH1 – Álfhóll 1. For the key, refer to Figure 4.

466 5.3.2 Kolbeinsárnes 4 (KB4) - 65°25.906' N, 21°11.992' W – Sill elevation: 2.24 ± 0.30 m a.s.l.

467 KB4 is found to the southwest of KB2 on the Kolbeinsárnes peninsula (Fig. 2D). The sediment core
468 contains a lower silty clay, organic-rich limus and overlying turfa peat (Fig. 8). The diatom
469 assemblage shows a transition from brackish-marine to freshwater dominance (Fig. 8).
470 Radiocarbon dating of a bulk sediment sample at the diatomological isolation contact at 100 cm
471 returned an age of 1890 – 2107 (2.0 k) cal. ka BP, which is employed for the SLIP. There is a
472 clear decrease in marine influence at KB4, representing a fall in RSL below 2.24 m a.s.l. at the
473 location.

474 5.3.3 Kolbeinsárnes 1 (KB1) - 65°25.984' N, 21°11.756' W – Sill elevation: 3.45 ± 0.30 m a.s.l.

475 KB1 is a small basin situated north of KB2 and northeast of KB4 (Fig. 2D). The stratigraphy
476 comprises of a basal blue-grey clay with silt, organic rich silt, olive-green limus with abundant
477 rootlets and a distinct uppermost olive-green limus layer (Fig. 8). The diatom assemblage
478 represents a gradual decrease in marine influence at the site (Fig. 8). A bulk sediment sample for
479 radiocarbon analysis from the diatomological isolation contact at 65 cm returned an age of 2185 –
480 2465 (2.3 k) cal. a BP for RSL falling below the SLIP.

481 5.3.4 Sandavatn 1 (SN1) - 65°20.249' N, 20°59.381' W – Sill elevation: 51.02 ± 0.30 m a.s.l.

482 SN1 is situated north of SN2 on the Heggstaðanes peninsula (Fig. 2D). A transect of 4 cores
483 produced a stratigraphy comprising a basal blue-grey silt, overlying limus layer and surface turfa
484 peat deposits. A tephra deposit was evident between the silt and limus layer at 578 cm, identified
485 as the Saksunarvatn tephra (10.2 cal ka BP) following geochemical analysis. Diatom analysis
486 reveals a transitional sequence from brackish to freshwater dominance (Fig. 8). A radiocarbon
487 sample at the apparent diatomological isolation contact at 610 cm produced a minimum age of
488 10814 – 11216 (11.1 k) cal. a BP for the SLIP.

489 5.3.5 Sandavatn 2 (SN2) - 65°20.026' N, 20°59.230' W – Sill elevation: 46.51 ± 0.30 m a.s.l.

490 SN2 is a large infilled basin also situated on the eastern side of the Heggstaðanes peninsula (Fig.
491 2D). The site stratigraphy was established through 4 cores and is characterised as a basal silt
492 overlain by organic rich limus containing a distinct tephra layer and an uppermost turfa peat layer.
493 The Saksunarvatn tephra was identified within the limus deposit at 509 cm, providing an age of
494 10.2 cal ka BP. In addition, a radiocarbon sample from an apparent diatomological isolation
495 contact at 610 cm (Fig. 8) gave a minimum isolation age of 11198 – 11327 (11.3 k) cal. a BP for
496 the SLIP. There is an indication of a reduced brackish influence at the site (at 614 cm), possibly
497 indicating a RSL lowering at the location.

498 5.3.6 Mýrar 1 (MY1) - 65°18.253' N, 21°02.401' W – Sill elevation: 57.90 ± 0.30 m a.s.l.

499 Mýrar is situated on the western side of the Heggstaðanes peninsula (Fig. 2D). The site
500 stratigraphy was established by a transect of 3 cores and comprises a basal gravel with overlying
501 blue-grey silts and clays, mixed organic sediments and uppermost peat layer. A number of
502 individual tephra layers were identified within the sedimentary profile. The diatom assemblage can
503 be divided into three distinct zones (Fig. 8). A radiocarbon sample was analysed from 612 cm and
504 returned an age of 11191 – 11311 (11.2 k) cal. a BP for the SLIP shown by the transition from
505 marine, brackish to freshwater dominance in the diatom flora. The Saksunarvatn tephra was also
506 identified at 592 cm, providing additional chronological control for the site (10.2 cal ka BP).

507 5.3.7 Álfhóll 2 (AH2) - 65°17.601' N, 20°55.978' W – Sill elevation: 68.22 ± 0.30 m a.s.l.

508 AH2 is a small basin ~110 m west of AH1 in innermost Heggstaðanes (Fig. 2D). A basal blue-grey
509 sand, overlain by silty clay and an olive-green limus is present within the cores. A dark grey tephra
510 was identified as Saksunarvatn at 594 cm following geochemical analysis, providing an age of 10.2
511 cal ka BP (Fig. 5 and 8). Diatom samples were analysed throughout the core sample showing
512 freshwater dominance but the lowermost samples provided insufficient diatoms to ensure a reliable
513 count (Fig. 8). A radiocarbon sample from 632 cm provided a limiting age for the deposition of
514 organic material and the site was therefore above RSL at 11109 – 11242 (11.2 k) cal. a BP.

515 5.3.8 Álfhóll 1 (AH1) - 65°17.657' N, 20°55.821' W – Sill elevation: 70.62 ± 0.30 m a.s.l.

516 AH1 is the highest basin investigated in Hrútafjörður-Heggstaðanes, situated to the northeast of
517 AH2 (Fig. 2D). The sediment stratigraphy was established through a transect of 3 cores and
518 comprises basal blue-grey clay and silty clay overlain by an olive-green limus. A dark grey tephra
519 layer was evident at 609 – 612 cm, which was identified as the Saksunarvatn tephra following
520 geochemical analysis, providing an age of 10.2 cal ka BP (Fig. 5 and 8). In total, nine diatom
521 samples were analysed, although the lowermost samples failed to produce sufficient diatoms to
522 ensure a valid count (Fig. 8). A radiocarbon sample at 613 cm produced an age of 10781 – 11174
523 (11.0 k) cal. a BP and acts as a limiting age for the site, although this should be treated with some
524 caution, given the close proximity to the Saksunarvatn tephra (10.2 cal. ka BP).

525 5.3.9 RSL curve for Hrútafjörður-Heggstaðanes

526 Six new SLIPs and two limiting points have been produced in Hrútafjörður-Heggstaðanes, the
527 innermost location along the research transect in NW Iceland. These new SLIPs have allowed the
528 construction of a tentative new RSL curve for the region, highlighting initial RSL fall and more
529 recent RSL changes (Fig. 6). The lack of mid-elevation sites in the region means that it has not
530 been possible to constrain RSL changes between ca. 11200 and 2400 cal. a BP (Fig. 6).
531 Pétursson (pers. comm, 2016) has measured the marine limit at 47 m a.s.l. in Hrútafjörður and 53
532 m a.s.l. in Hvammstangi (east of Heggstaðanes), which provide a similar constraint on maximum
533 postglacial RSL as MY1 (58 m a.s.l.) where a clear transitional sequence is evident. AH1 and AH2

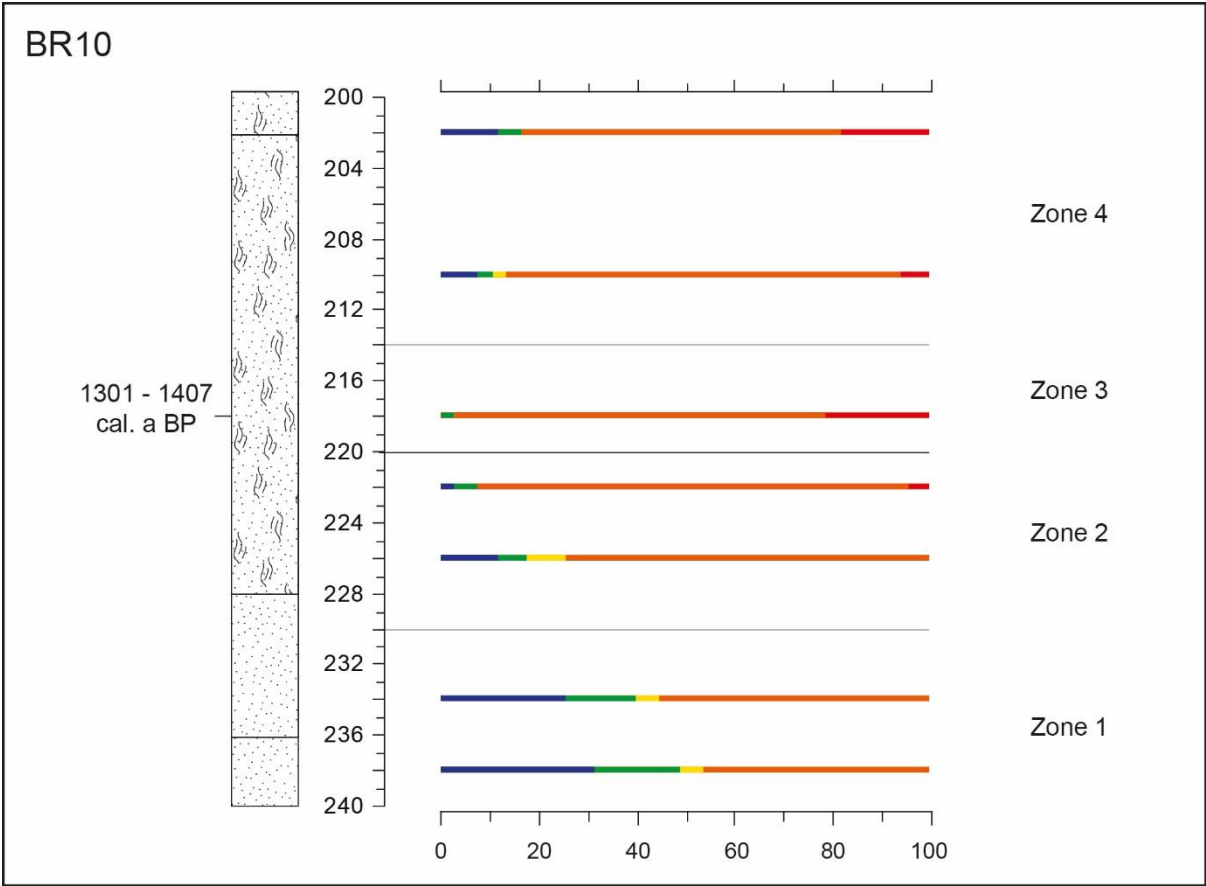
534 act as limiting RSL points, suggesting that RSL has most likely been below this level since
535 deglaciation.

536 5.4 Breiðavík-Látrar (Area E (Fig. 2); one site)

537 A series of sites were investigated in the Breiðavík-Látrar area in order to investigate the high
538 marine limit elevations recorded in the region. A number of higher elevation sites recorded
539 evidence for marine influence, yet suffered from poor chronological control, and thus are not
540 presented here. Consequently, only one site is presented here in full, from close to present sea
541 level (Fig. 9). The elevational data from the higher sampled sites can however be seen in Fig. 6.

543 5.4.1 Breiðavík 10 (BR10) - 65°32.631' N, 24°25.081' W – Sill elevation: 4.40 ± 0.30 m a.s.l.

544 The BR10 locality is situated in Breiðavík, a large bay on the westernmost part of Iceland (Fig. 2E).
545 The site stratigraphy can be summarised as a basal sand overlain by silt-rich limus and organic
546 rich silts, with visible shell remains likely deposited into the basin by aeolian transport. The diatom
547 record shows a reduction and subsequent increase in marine influence at the location, with the
548 diatomological isolation contact therefore identified at 218 cm (Fig. 9). A bulk radiocarbon sample
549 from 218 cm produced an age of 1301 – 1407 (1.4 k) cal. a BP.



550
551 *Figure 9: Summary diatom assemblages and stratigraphic profile for Breiðavík 10 in Breiðavík-Látrar,*
552 *showing the key environmental changes recorded. For the key, refer to Fig. 4.*

553
554 5.4.2 RSL record from Breiðavík-Látrar

One new SLIP has been generated for the region (see Table 1), which is supported by the local marine limit at ~85 m a.s.l. by Norðdahl and Pétursson (2005). Prominent shorelines have been identified at intermediate elevations (38 m and 79 m a.s.l. at Seljavík, southwest of BR10 (Pétursson, pers. comm, 2016). Additional sites with brackish diatoms were recorded at ~64 m, 67 m and 73 m a.s.l. (Fig. 9) but suffered from poor chronological control. It is likely that organic productivity was low immediately following deglaciation and as a result, limited organic material was available for dating within these sediment sequences. The ages generated are not consistent with the elevation of the samples and thus probable timing of isolation.

563

6. Discussion

565

6.1 RSL changes in northwest Iceland

Investigation of isolation basin, coastal lowland and geomorphological evidence has allowed the reconstruction of RSL changes at four locations in NW Iceland. The reconstructed patterns of RSL changes allow the testing of the contrasting uplift hypotheses, with the results having implications for GIA modelling, ice sheet configuration and deglacial pattern, as well as meltwater input into the North Atlantic.

6.1.1 Hlöðuvík and Rekavík bak Látrum

In Hlöðuvík and Rekavík bak Látrum, the new RSL data provide constraint on marine limit formation. The marine limit in Hlöðuvík is recorded at $\sim 17.5 \pm 1.0$ m a.s.l. and is characterised by a basal till overlain by marine sediments and an upper till (15-26 m a.s.l., Hjort *et al.*, 1985). Lake basin samples from close to the marine limit demonstrate entirely freshwater assemblages and therefore support the interpretation of this feature. The presence of the Saksunarvatn tephra in these lake basin sediments suggests that the lower part of the valley was ice free by 10.2 cal ka BP and provides a limiting (minimum) age for local marine limit formation. This interpretation is supported by Hjort *et al* (1985) who identified that the Saksunarvatn tephra was deposited close to sea-level, suggesting that RSL was below the elevation of the lake basin sites at 10.2 cal. a BP.

In Rekavík bak Látrum, following deglaciation RSL fell from the local marine limit at 15-25 m a.s.l. (Hjort *et al.*, 1985). This RSL fall is constrained by the new RSL data to between 9.3 cal. ka BP and 10.2 cal. a BP, which acts as both the minimum age for marine limit formation and deglaciation. Additional sites explored in Rekavík bak Látrum demonstrate extensive gravel and sand deposits, limiting the potential for reconstructing environmental change for the westernmost section of the study area.

6.1.2 Reykjanes-Laugardalur

589 Following deglaciation, RSL fell from the local marine limit at ~30 m a.s.l. at ca. 10.6 cal ka BP until
590 9.3 cal. ka BP, after which RSL fell below present (Fig. 6). The RSL record generated in
591 Reykjanes-Laugardalur therefore demonstrates that deglaciation may have occurred at a later date
592 (10.6/11.9 cal. ka BP, GR1/VAT2) in Ísafjarðardjúp than north of Breiðafjörður (Lloyd *et al.*, 2009
593 [ca. 14.1 cal. ka BP]) and on the north coast of Snæfellsnes (Brader *et al.*, 2015 [ca. 12.7 cal. ka
594 BP]). The fall of RSL below present during the early Holocene (9.3 cal. ka BP) in this area can be
595 compared with dates for a similar fall below present elsewhere in NW Iceland of ca. 9.0 cal ka BP
596 (estimated for Bjarkarlundur, Lloyd *et al.*, 2009); ca. 10.1 cal. ka BP (Snæfellsnes, Brader *et al.*,
597 2015); >10.2 cal ka BP (Skagi Peninsula, Rundgren *et al.*, 1997); and ca. >10.5 cal ka BP in
598 southwest Iceland (Ingólfsson *et al.*, 1995; Pétursson *et al.*, 2015).

599 The new early Holocene RSL data from Reykjanes-Laugardalur can be compared to
600 palaeoceanographic studies in Ísafjarðardjúp, which note a termination of glacio-marine conditions
601 within the fjord by ca. 10.2 cal. ka BP and a lowered RSL between ca. 10.6 and 8.9 cal ka BP
602 (Quillman *et al.*, 2010). At Reykjanes-Laugardalur, our new sea-level data indicate glacier retreat
603 by at least 10.6 cal ka BP (Fig. 6) leading to glacio-isostatic unloading and a subsequent fall in
604 RSL, which can be compared with the results from Quillman *et al.* (2010) in inner Ísafjarðardjúp.
605 The difference in deglacial age is possibly the consequence of later glacier retreat at the innermost
606 part of the fjord system due to lesser ingress of the warm Irminger Current, which would have
607 become fully established in NW Iceland by ca. 10.2 cal. ka BP (Ólafsdóttir *et al.*, 2010).

608 Following the RSL fall below present sea level in the early Holocene (Fig. 6), a transgression must
609 have occurred in the mid- to early Holocene, with the Reykjanes-Laugardalur RSL curve showing
610 an associated regression from the proposed mid-Holocene highstand at ca 3.9 cal. ka BP (Fig.
611 6). The elevation and timing of this proposed highstand fit well with previous evidence from
612 Ísafjarðardjúp, such as the raised beach surveyed by Principato (2008) at 5 m a.s.l. and dated to
613 3.5 cal. ka BP (3612 ± 40 ^{14}C a BP, marine shell). The SLIPs from Reykjanes-Laugardalur provide
614 a minimum elevation of the proposed highstand which corresponds with both previous isolation
615 basin records from NW Iceland (Lloyd *et al.*, 2009) and the *Nucella* transgression (e.g. Símonarson
616 and Leifsdóttir, 2002).

617 RSL appears to have fluctuated over the late Holocene in Reykjanes-Laugardalur, with RSL rise
618 most recently, as shown by the radiocarbon ages from SHV1 (1.25 ± 0.30 m a.s.l.; 2.1 cal ka BP
619 and 2.3 cal ka BP), the age of the proposed Little Ice Age shoreline in Ísafjarðardjúp (0.3-0.5 m
620 a.s.l.; 162 [0-267] cal. a BP; Principato, 2008), and the age of the BB1 sample (-0.50 ± 0.25 m
621 a.s.l.; 'modern'). Poor chronological control on the BB1 sample prevents a recent rate of RSL
622 change being calculated, although RSL must have risen to present from this saltmarsh peat
623 deposit, situated just below present sea-level.

624 6.1.3 Hrútafjörður-Heggstaðanes

625 The isolation basin records from Hrútafjörður-Heggstaðanes constrain the highest elevation
626 reached by postglacial RSL in the region. Despite the lack of direct evidence for a raised
627 shoreline, it is proposed that the marine limit lies between ~47 and 58 m a.s.l., with a minimum
628 timing for deglaciation of 11.2 cal. ka BP (Fig. 6).

629 The highest recorded marine influence along Hrútafjörður (~58 m a.s.l.; MY1) is higher than the
630 previously reported but undated marine limit in innermost Hrútafjörður at about 50 m a.s.l.
631 (Ingólfsson, 1991). However, previous research in northern Iceland has noted a southerly
632 decrease in marine limit elevations due to differences in deglacial timing (Norðdahl and Pétursson,
633 2005). In Hrútafjörður, it is likely that the marine limit formed during the Younger Dryas, based on
634 the known extent of the ice sheet during this period (e.g. Pétursson *et al.*, 2015). As a result, the
635 marine limit features are assigned a tentative Younger Dryas age, given the lack of dateable
636 material to confirm the age of this feature.

637 6.1.4 Breiðavík-Látrar

638 The new late Holocene data from Breiðavík-Látrar provides a valuable constraint on recent RSL
639 changes in outermost Breiðafjörður, suggesting a rise in RSL since ca 1.4 cal ka BP. Investigation
640 of higher elevation basins in the region provides evidence for marine influence up to 67 m a.s.l.;
641 however, poor chronological control limits constraint of a regional RSL curve, likely as a
642 consequence of low productivity immediately following deglaciation, leading to low organic content
643 within dated bulk sediment samples. Investigation of the geomorphology of the area provides
644 support for a marine limit ~85 m a.s.l. (Norðdahl and Pétursson, 2005; Fig. 6), with shorelines at
645 ~38 and 79 m a.s.l.

646 6.2 Geomorphological evidence vs. hypothesised RSL patterns

647

648 The investigation of postglacial RSL change provides an opportunity to explore patterns of
649 postglacial uplift across NW Iceland. As outlined in Fig. 3 and Fig. 6, contrasting patterns of RSL
650 change would be expected in the four research locations studied under the two uplift scenarios. In
651 particular, the elevation of the marine limit is an important factor in establishing the most likely ice
652 loading/unloading scenario, which can be summarised as:

653 a) Central uplift scenario: there was a single uplift and therefore ice loading centre, with ice
654 emanating from central Iceland and so the highest marine limits are expected in Hrútafjörður-
655 Heggstaðanes and lower marine limits are proposed in Hlíðuvík and Rekavík bak Látrum (and
656 Breiðavík-Látrar), or;

657

658 b) Local uplift scenario: there were multiple uplift centres (with localised glaciation in NW
659 Iceland) and thus a concurrent, separate and independent ice cap was centred over Vestfirðir. As
660 a result, if deglaciation was rapid, the highest marine limit would be found in Reykjanes-
661 Laugardalur due to greater ice thickness resulting from the independent ice cap (Fig. 3) under the
662 hypothesised scenario.

663 It is clear from the hypothesised RSL curves that the lowest marine limit elevation along the
664 research transect is expected in Hlíðuvík and Rekavík bak Látrum (Fig. 3 and 6). In Reykjanes-
665 Laugardalur, higher marine limit elevations would be anticipated under a local uplift centre due to
666 the proximity to the proposed centre of secondary (local) ice loading in NW Iceland (Fig. 3 and
667 6). However, our new RSL data suggest that this region experienced later glacial retreat than
668 elsewhere in NW Iceland, meaning that higher shorelines could not have formed due to the
669 presence of ice cover. In Hrútafjörður-Heggstaðanes, the greatest contrast in marine limit
670 elevation is anticipated by the hypothesised RSL scenarios (Fig. 3 and 6). Under the central
671 Iceland uplift scenario, the marine limit would be highest due to increased proximity to the central
672 Iceland ice loading centre (Fig. 3). In contrast, an intermediate elevation is expected under the
673 local ice loading centre scenario due to its location between the two proposed ice loading centres
674 (local and central).

675 Hlíðuvík and Rekavík bak Látrum are the northwesternmost terrestrial locations in this study and
676 ice thicknesses were likely to be thinnest as they are furthest from the centres of uplift. This
677 hypothesis is supported by the raised shoreline and lake basin evidence from the region estimating
678 a marine limit of ~25 m, which is slightly lower than in Reykjanes-Laugardalur (~30 m a.s.l.) and
679 considerably lower than in Hrútafjörður-Heggstaðanes (~58 m a.s.l.) (Fig. 6). Figure 6
680 demonstrates an increased marine limit elevation from Hlíðuvík and Rekavík bak Látrum to
681 Reykjanes-Laugardalur and Hrútafjörður-Heggstaðanes (Fig. 6). We therefore associate lesser
682 uplift with thinner ice loading as glacio-isostatic uplift occurred rapidly close to the retreating LGM
683 IIS (Norðdahl and Ingólfsson, 2015).

684 Similar to Hlíðuvík and Rekavík bak Látrum, Breiðavík-Látrar, the westernmost location studied, is
685 also situated at a location far from the proposed centre of uplift in central Iceland and thus the
686 hypothesised RSL patterns are for an extreme terrestrial location from the uplift centre (Fig. 6).
687 However, geomorphological evidence from Breiðavík-Látrar suggests greater uplift than in
688 Hlíðuvík and Rekavík bak Látrum, with raised shorelines recorded at 85 m, 79 m, 64 m and 38 m
689 a.s.l., exceeding those elevations recorded at Hlíðuvík and Rekavík bak Látrum (~ 25 m a.s.l.),
690 Reykjanes-Laugardalur (~ 30 m a.s.l.), and Hrútafjörður-Heggstaðanes (~ 58 m a.s.l.) except for
691 the 38 m a.s.l. shoreline. There are two possible explanations for this difference in marine limit
692 elevation between Breiðavík-Látrar and Hlíðuvík and Rekavík bak Látrum:

693 a) Breiðavík-Látrar experienced early deglaciation and records uplift from multiple ice loading
694 centres (localised glaciation and regional (central) glaciation), or;

695 b) Breiðavík-Látrar experienced earlier deglaciation and underwent greater uplift due to rapid
696 retreat (of thicker ice) from Breiðafjörður, the site of a proposed major ice stream.

697 Breiðavík-Látrar and Hlöðuvík and Rekavík bak Látrum are not directly comparable due to the
698 differences in potential ice accumulation within major fjord and smaller valley systems. The limited
699 chronological control on the geomorphological features present in Breiðavík-Látrar means that it is
700 not possible to differentiate between these two hypothesised explanations. Our preferred scenario
701 is that of central uplift, as evidenced by the increased elevation of the marine limit with proximity to
702 the ice loading centre in central Iceland. However, the geomorphological evidence in Breiðavík-
703 Látrar may record uplift from multiple sources (i.e. a combination of central uplift and local uplift
704 from Vestfirðir) and thus the local uplift scenario cannot be unequivocally rejected. Future glacio-
705 isostatic adjustment modelling may be able to assist in differentiating between these two possible
706 interpretations.

707 The RSL curves from Hrútafjörður-Heggstaðanes and Reykjanes-Laugardalur provide insights into
708 rates of initial RSL changes following Lateglacial to early Holocene deglaciation, particularly when
709 compared to previous records of RSL change in the region (Lloyd *et al.*, 2009; Brader *et al.*,
710 2015). In Hrútafjörður-Heggstaðanes, initial RSL fall occurred rapidly shown by the cluster of
711 similar ages in basins of different elevation (Fig. 6). This rapid RSL fall corresponds with the
712 results from Lloyd *et al.* (2009) and Brader *et al.* (2015), despite differences in deglacial timing,
713 which both demonstrate rapid RSL fall in southern Vestfirðir and northern Snæfellsnes following
714 deglaciation. It should however be noted that very high rates of RSL fall close to the margin of a
715 glacier and at an earlier date have been recorded in western Iceland (Norðdahl and Ingólfsson,
716 2015). It is clear that proximity to the glacier edge of individual data points is therefore an
717 important consideration when assessing regional signals.

718 In contrast, Reykjanes-Laugardalur demonstrates a lower rate of initial RSL fall, likely as a product
719 of proximity to the local centre of uplift and the configuration of individual fjord systems. The
720 complex geomorphology of Ísafjarðardjúp may have promoted a slower rate of ice retreat than
721 seen in wider fjord systems and thus led to a reduction in the rate of initial RSL fall due to lower
722 rates of uplift. Alternatively, rapid deglaciation of the fjord system and thus high rates of uplift may
723 have led to equilibrium between eustatic sea-level rise and isostatic uplift within the region, leading
724 to the slower rates of RSL fall (e.g. Norðdahl and Ingólfsson, 2015).

725 Late Holocene RSL records from NW Iceland suggest high spatial variability in recent RSL
726 changes. In southern Snæfellsnes (Gehrels *et al.*, 2006; Saher *et al.*, 2015) and Reykjanes-
727 Laugardalur (this study), low elevation coastal lowland and isolation basin sites provide evidence

728 for recent RSL rise. In contrast, records from Hrútafjörður-Heggstaðanes (this study) suggest
729 recent RSL fall, with assumed RSL fall to present also noted in southern Vestfirðir (Lloyd *et al.*,
730 2009) and northern Snæfellsnes (Brader *et al.*, 2015). Additional low elevation sites are required
731 for locations throughout NW Iceland to further explore this variability.

732 The four new RSL records from NW Iceland allow the testing of two uplift (ice loading) scenarios.
733 There is evidence to support the central uplift scenario along the research transect, based on the
734 increased marine limit with proximity to the proposed ice loading centre (Fig. 6). There is however
735 complexity within the uplift patterns presented, with the results from Breiðavík-Látrar suggesting
736 that uplift from multiple ice loading centres cannot be excluded. Despite this complexity, our
737 preferred scenario is that of central uplift with ice emanating from central Iceland.

738 6.3 Implications for Icelandic uplift (ice loading) scenarios

739 Offshore and onshore evidence suggests that substantial sectors of the LGM IIS were marine-
740 based, extending to the shelf edge in a number of locations (Ólafsdóttir, 1975; Ingólfsson and
741 Norðdahl, 2001; Norðdahl and Pétursson, 2005; Hubbard *et al.*, 2006; Norðdahl and Ingólfsson,
742 2015). Marine-based sectors of ice sheets are particularly sensitive to changes in sea level
743 (Hubbard, 2006) and ocean temperature (Schmidtke *et al.*, 2014). Consequently, increases in the
744 rate of eustatic sea-level rise associated with deglaciation of the major Northern Hemisphere ice
745 sheets and correspondingly warmer surface waters would have had significant impacts on the IIS
746 (Norðdahl and Ingólfsson, 2015). This would have led to a retreat of the grounding line, thinning of
747 the ice sheet and increased rates of calving eventually leading to flotation and collapse of marine
748 based sectors of the ice sheet, as posited elsewhere in western Iceland (Norðdahl and Ingólfsson,
749 2015). Some of the highest but as yet undated marine limits may originate from this period, such
750 as those recorded in Breiðavík-Látrar (Norðdahl and Pétursson, 2005).

751 The new RSL curves from NW Iceland demonstrate an initial period of rapid early Holocene RSL
752 fall, particularly in Hrútafjörður-Heggstaðanes (11.1-11.3 cal. ka BP) and in Reykjanes-Laugardalur
753 (ca 10.2-10.6 cal. ka BP), indicating rapid glacio-isostatic uplift following deglaciation. Rapid rates
754 of uplift support a more or less instantaneous response of the Icelandic lithosphere to the removal of
755 ice loading, likely as a consequence of rapid ice retreat (Norðdahl and Ingólfsson, 2015).

756 The new RSL data provide an insight into possible uplift scenarios in Iceland, with the preferred
757 central uplift scenario being supported by evidence from the research transect. GIA modelling will
758 allow the contrasting uplift scenarios to be further tested. The new RSL data generated will act as
759 a valuable constraint for such models through the establishment of deglacial timing, age of marine
760 limit formation, marine limit elevation, and subsequent Lateglacial to Holocene RSL changes. At
761 present, there are few Lateglacial to Holocene RSL records for Iceland (Rundgren *et al.*, 1997;
762 Lloyd *et al.*, 2009; Brader *et al.*, 2015) and as such, these new data provide an opportunity to

763 better constrain GIA model outputs than previously possible. As a result, the complexity of uplift in
764 NW Iceland can also be tested to further explore the implications of the Breiðavík-Látrar record on
765 GIA models.

766 6.4 Implications for thermohaline circulation

767 It is clear that the rapid deglaciation evident from the RSL records generated from NW Iceland
768 suggest significant freshwater input to a sensitive region of the North Atlantic which would
769 influence oceanic circulation in the region. Modelling studies have demonstrated the weakening of
770 AMOC and cooling of the North Atlantic following freshwater input from non-Icelandic sources (Le
771 Grande *et al.*, 2006; Clarke *et al.*, 2009), which has also been supported by proxy datasets
772 (McManus *et al.*, 2004; Thornalley *et al.*, 2010). However, the influence of meltwater from the LGM
773 IIS is less well explored. It is therefore important to better understand the LGM ice extent in
774 Iceland and patterns of deglaciation, to provide constraints on models of the interactions between
775 the IIS and surrounding ocean (Ingólfsson *et al.*, 2010).

776 The new RSL data provide constraint on glacio-isostatic uplift in NW Iceland and whilst there is
777 evidence to support the central uplift scenario, there is also evidence for regional complexity in
778 deglaciation (and therefore uplift). The differences in rates of RSL change between study locations
779 point towards a non-uniform pattern of deglaciation and thus suggest that freshwater input from
780 different fjord systems may not have occurred at the same rate throughout NW Iceland. This has
781 important implications for the timing and location of freshwater input into the North Atlantic and the
782 new RSL data will therefore provide important constraint on models of ice sheet-ocean interaction.

783 7. Conclusions

784 Isolation basin and coastal lowland evidence from NW Iceland demonstrates spatial variability in
785 RSL changes recorded in the region. These differences are shown through the elevation of the
786 local marine limit in Hlíðuvík and Rekavík bak Látrum (NW), Reykjanes-Laugardalur (central) and
787 Hrútafjörður-Heggstaðanes (SE), as well as the rates of subsequent RSL changes. There is also
788 evidence for RSL fall below present sea level during the early Holocene. Currently, the minimum
789 RSL position during this period is poorly constrained, but RSL likely fell no lower than 40 m below
790 present in the early Holocene (Ingólfsson *et al.*, 1995) but may have fallen about 85 m below
791 present sea level in late Bølling and early Allerød times (Norðahl and Ingólfsson, 2015). It is clear
792 from the RSL histories generated in Reykjanes-Laugardalur (central) and Hrútafjörður-
793 Heggstaðanes (SE) that RSL must have risen to a mid-Holocene highstand, which correlates well
794 with geomorphological evidence from the region, as well as one previous isolation basin study
795 (Lloyd *et al.*, 2009).

796 Evidence from the research transect has allowed the testing of the different uplift scenarios. The
797 increased elevation of the marine limit with proximity to the proposed uplift (and therefore ice
798 loading) centre in central Iceland provides support for the central uplift hypothesis. This is further
799 compounded by higher concurrent RSL throughout the Holocene in Hrútafjörður-Heggstaðanes
800 (SE) compared to Reykjanes-Laugardalur (central) or Hlöðuvík and Rekavík bak Látrum (NW, see
801 Fig. 3 and 6). The high elevation of the local marine limit in Breiðavík-Látrar (SW) highlights the
802 complexity of uplift and deglaciation patterns in NW Iceland.

803 Future GIA modelling may help to further differentiate between the potential uplift scenarios
804 through integration of the new RSL data on timing of deglaciation, marine limit age and elevation,
805 and RSL changes. In addition, the new data are important constraints on ice sheet-ocean
806 interaction models. In particular, the constraint of deglacial pattern and timing will assist in the
807 modelling of freshwater input into sensitive areas of the North Atlantic.

808 **8. Acknowledgements**

809 MDB was supported by an RGS-IBG Postgraduate Research Award, BGS Postgraduate Award,
810 Van Mildert College Postgraduate Award, QRA Dudley Stamp Memorial Award and a Van Mildert
811 College Principal's Award. Support in the field was provided by Sam Gunter, Harry Inman, Chris
812 Darvill and Matthew Edwards. The authors would like to acknowledge the support of NERC
813 Radiocarbon Allocations (Allocation No. 1689.0313 and 1748.1013) and NERC TAU Support
814 (NERC TAU78/1012) and the assistance of Chris Hayward with electron microprobe analyses. We
815 would also like to thank *RANNÍS* (The Icelandic Centre for Research) and *Umhverfisstofnun*
816 *Íslands* for permission to undertake the research in Iceland. We also thank two anonymous
817 reviewers for their valuable comments, which greatly improved the manuscript.

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Table 1: New SLIPs and limiting ages from Hlöðuvík and Rekavík bak Látrum, Reykjanes-Laugardalur, Hrútafjörður and Heggstaðanes, and

Site Code	Lab Code	¹⁴ C age (1σ) BP	cal. age (2σ) BP	Uncorr. sill/ core elev. (m MHWST-sill)	Corr. sill/core elev. (m a.s.l.)	Core depth (cm)	Reference wtr. level	Indicative Meaning (m)	Relative sea level (m)
REK1	SUERC-54842	8275 ± 39	9130 – 9412	17.5 ± 0.15	18.63 ± 0.3	330	MHWST	1.1 ± 0.3	17.7 ± 0.6
HD3	Saksunarvatn	-	10175 – 10245	16.91 ± 0.15	18.01 ± 0.3	134	>HAT	N/A	Limiting
BB1	SUERC-47973	MODERN	N/A	-0.5 ± 0.15	-0.5 ± 0.25	16	N/A	N/A	N/A
SHV1	SUERC-47963	2123 ± 35	1996 – 2299	0.2 ± 0.15	1.25 ± 0.3	218	MHWST	1.05 ± 0.3	0.2 ± 0.6
SHV1	SUERC-47964	2269 ± 35	2158 – 2349	0.2 ± 0.15	1.25 ± 0.3	228	MHWST-MTL	0.65 ± 0.55	0.6 ± 0.85
VHF1	SUERC-47967	4886 ± 36	5584 - 5711	3.45 ± 0.15	4.5 ± 0.3	69	MHWST	1.05 ± 0.3	3.45 ± 0.6
RK3	SUERC-47965	3602 ± 37	3829 - 4071	5.15 ± 0.15	6.2 ± 0.3	147	MHWST	1.05 ± 0.3	5.15 ± 0.6
RK6	SUERC-47966	8299 ± 38	9139 - 9432	1.25 ± 0.15	2.3 ± 0.3	100	MHWST	1.05 ± 0.3	1.45 ± 0.6
RK10	SUERC-47970	8894 ± 41	9798 - 10190	15.45 ± 0.15	16.5 ± 0.3	238	MHWST	1.05 ± 0.3	15.45 ± 0.6
VAT1	SUERC-47971	8947 ± 39	9918 - 10216	21.15 ± 0.15	22.2 ± 0.3	204	MHWST	1.05 ± 0.3	21.15 ± 0.6
VAT2	SUERC-47972	10188 ± 42	11712 - 12067	28.45 ± 0.15	29.6 ± 0.3	428	>HAT	N/A	Limiting
GR1	SUERC-48877	9377 ± 47	10444 - 10724	27.45 ± 0.15	28.5 ± 0.3	212	MHWST	1.05 ± 0.3	27.55 ± 0.6
KB1	SUERC-54844	2332 ± 37	2185 - 2465	2.75 ± 0.15	3.45 ± 0.3	65	MHWST	0.7 ± 0.25	2.75 ± 0.55
KB2	SUERC-54845	338 ± 37	308 - 484	0.4 ± 0.15	1.09 ± 0.3	30	HAT	1.2 ± 0.25	-0.1 ± 0.55
KB4	SUERC-54846	2024 ± 37	1890 - 2107	1.55 ± 0.15	2.24 ± 0.3	100	MHWST	0.7 ± 0.25	1.55 ± 0.55
MY1	SUERC-54839	9831 ± 42	11191 - 11311	57.2 ± 0.15	57.9 ± 0.3	612	HAT	1.2 ± 0.25	56.7 ± 0.55
SN1	SUERC-47986	9689 ± 40	10814 - 11216	50.3 ± 0.15	51.02 ± 0.3	610	MHWST	0.7 ± 0.25	50.3 ± 0.55
SN2	SUERC-47987	9850 ± 41	11198 - 11327	45.8 ± 0.15	46.51 ± 0.3	610	MHWST	0.7 ± 0.25	45.8 ± 0.55
AH2	SUERC-47974	9751 ± 41	11109 - 11242	67.5 ± 0.15	68.22 ± 0.3	632	HAT	N/A	Limiting
AH1	SUERC-47985	9625 ± 40	10781 - 11174	69.9 ± 0.15	70.62 ± 0.3	613	>HAT	N/A	Limiting
BR10	SUERC-54849	1465 ± 35	1301 - 1407	2.9 ± 0.15	4.4 ± 0.3	218	MHWST	1.5 ± 0.3	2.9 ± 0.6

Breiðavík-Látrar, NW Iceland.